Reusable Launch Vehicles and Space Operations

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Abstract

As a result of technological progress, we are now on verge of developing cost-effective reusable launch vehicles (RLV) for space. This study reviews the strategic implications of the emerging vision within the U.S. Department of Defense for using these vehicles. Although the U.S. Air Force is making the transition to a force that relies increasingly on space, the best path does not necessarily involve replicating the traditional air missions in space. This study of potential missions for RLVs concludes that, while these are capable of numerous missions (e.g., reconnaissance, global strike, cargo and personnel transport), the most important mission for the immediate future for both the U.S. military and commercial firms is in the area of traditional spacelift. The two broad conclusions that emerge from this study are that the U.S. military should move away from the spacelift business by obtaining spacelift through commercially procured launch services, and second, that the U.S. military should not develop militarized RLVs that are designed to perform the traditional air operations in space.

I. Introduction

The survival and prosperity of the United States depends in part on its ability to exploit space and use space-based assets for a variety of national purposes. The U.S. Air Force and Department of Defense recognize that the role of space is critical to U.S. security interests.[1] At present, the U.S. Department of Defense (DoD) exploits space primarily by launching and operating a wide variety of sophisticated satellites, which provide a wealth of intelligence, surveillance, and reconnaissance information, as well as vital communications, navigation, early-warning, and environmental monitoring services. The commercial industry also exploits space on a worldwide basis, and the preponderance of its activity in the communications arena.

By any standard, space is big business. It is forecasted that more than $500 billion in both public and private funds will be invested in space on a global basis between 1998 and 2000.[2] Space activity is a truly global enterprise in which more than 1,100 commercial companies in 53 countries are engaged in developing, manufacturing, and operating space systems.[3] In the case of the United States, $100 billion is being invested in space today, and that level of investment is increasing.[4] At least 500 U.S. companies are directly involved with space activity, with revenues projected to be $122 billion in 2000.[5] As of mid-1999, 27 states in the United States are seeking to expand space activity, as exemplified by the development of licensed commercial spaceports.[6]

While the future is indeed bright for the expansion of governmental and commercial space activity, the high costs of getting into space remain the most serious impediment to fully realizing the potential offered by space. On the governmental side, the U.S. Air Force Evolved Expendable Launch Vehicle program focuses on reducing the costs of spacelift through derivatives of existing boosters. The program goal is a 25 percent reduction in the cost of spacelift and the hope that a 50 percent reduction in costs can be achieved.[7] If this cost reduction is achieved, it will be a significant step in the right direction, but it should be noted that cost reductions on the order of 10-100 times current cost are needed if we are to fully exploit space.[8] This means that the United States needs to reduce the cost of access to space as well as continue to design, build, operate, sustain, and protect our space-based assets. At the same time, the United States may want the capability to deny space operations to other states.

The concept of RLVs is to substantially reduce launch costs and thereby provide "routine" access to space as well as dramatically expand the ability of the United States to operate in space. This study examines the utility of reusable launch vehicles as it relates to the use of space for military and commercial purposes.

For the purposes of this study, RLVs are defined as vehicles that are capable of carrying at least 20,000 pounds into low Earth orbit, returning to Earth for servicing, and then performing another mission within days. A number of concepts for RLVs have been proposed, including single-stage to orbit, two-stage to orbit, and Trans-atmospheric vehicles, all of which seek routine access to space at greatly reduced cost. While none of the concepts for RLVs have reached this elusive goal, it is possible for the United States to produce a reusable launch vehicle within the next ten years if it makes a significant investment in technology. This study does not focus on the performance of RLVs, but examines the more significant military missions and commercial applications for RLVs and their strategic implications.[9]

The principal theme that emerges from this study is that, while the pursuit of traditional air power roles in space with RLVs is a logical and perhaps inevitable progression from current technology, it is unwise to design these vehicles for specifically military applications. The U.S. national objective should be to reduce the cost of access to space, which implies that the first generation RLV should be designed to minimize commercial cost rather than maximize military performance.[10] While a number of national security benefits are associated with RLVs, it is critical for civil or commercial firms, rather than the military, to dominate the development of RLVs for the United States. Indeed, the military pursuit of a militarized RLV may be counterproductive because it may encourage adversaries as well as allies to engage in the behavior that the U.S. seeks to deter, most notably an arms race in space.

There are differing perspectives within the U.S. Department of Defense on the strategic implications of developing RLVs for military purposes. A dominant theme in the current debate is to "weaponize space" once RLVs are available, and thus to use RLVs to accomplish traditional air power missions, including control and precision engagement, among others.

This study begins with the argument that space is a growth industry, that the exploitation of space is vital to U.S. national security, and that the United States must reduce the cost of access to space. The emergence of RLVs will influence how all nations and industries exploit space in the future.

The next section reviews the history of the development of RLVs and current concepts and programs. One conclusion that emerges from this review is that it is possible to develop RLVs in the relatively near future. Section Three analyzes the potential missions and applications of RLVs for both the military and industry. In the case of military missions, this study examines the U.S. Air Force Space Command's concept of operations for a space operations vehicle as well as various industrial applications. The study concludes with recommendations for how the United States should proceed with the development of RLVs.

II. Understanding the Development of Reusable Launch Vehicles

In March 1998, the U.S. Space Command released its long-range plan for the year 2020, which examined how the future environment would affect space operations. In so doing, this plan identified six key themes, including market forecasts for potential missions, the history of RLVs, technical challenges, economic considerations, national and international policy, and the potential threats facing reusable launch vehicles.[11] The most fundamental reason for developing RLVs is profit.

Space Activity Forecast

The key to exploiting space is to have satellites on orbit. In the early days of satellites, the government was the only customer, but commercial satellite users soon entered the market. In 1996 commercial launches exceeded military launches for the first time in the United States.[12] Today, 75 percent of all satellites launched worldwide are commercial, and it is likely that the commercial sector will dominate the space industry.[13]

This shift is reinforced by a review of projected launch rates. By the year 2007, it is estimated that roughly 1,700 commercial communication satellites will be launched.[14] During this same period, it is predicted that only 129 Western military satellites will be launched, which is only 10 percent of all launches worldwide.[15] The demand for launch services continues to increase dramatically, as exemplified by the fact that roughly 2,700 satellites will be launched through the year 2017.[16] This is an explosive level of growth given that there are roughly 600 active satellites on-orbit today, of which 134 were launched in 1998.[17] The economic impact of space and space-based services is large today and growing.

Today, the United States places satellites into orbit primarily with unmanned, one-time use or expendable boosters that are derived from intercontinental ballistic missiles developed in the 1950s and 1960s. This approach worked well for years. While the space launch business could hardly be called routine, it has become very profitable for the firms that provide launch service worldwide. Production forecasts bear this out, predicting that 1,700 expendable launch vehicles worth roughly $110 billion will be produced over the next 20 years in response to the growing demand for launch services.[18]

The entry of more firms into the launch services market increases competition. The actual cost of a launch service has always been an important consideration among buyers, but launch availability and reliability are also important factors. The future leader in the business of providing launch services must be able to beat competitors in terms of availability, price, reliability, and launch flexibility. The key objective is to develop a space launch capability that is routine, reliable, flexible, and affordable. The company that succeeds in developing the first practical RLV will capture a substantial share of the global market for spacelift.

Emerging concepts for commercial space operations might use RLVs for satellite servicing, manufacturing, space tourism, and the transportation of cargo or personnel through space. One study indicates that the commercial market may support a high-speed, point-to-point parcel delivery service with delivery prices up to $500 per pound.[19] Another study suggests that while space tourism is highly sensitive to price, it is a potentially profitable area.[20] Other studies estimate that some RLVs could generate more than ten times the daily revenue of current cargo aircraft, but at only twice the cost.[21] Given that these potential commercial space activities are all contingent on low cost access to space, the worldwide commercial space industry, private investors, and the United States government all are investing in various RLV concepts.[22]

The United States Government is interested in RLVs for both civil and military reasons. On the civil side, the Space Shuttle will eventually require replacement, even though the plan is for the Shuttle to perform the bulk of the space lift that is necessary to construct the international space station. The vehicle that replaces the Space Shuttle will perform the bulk of resupply missions for the international space station. On the military side, the Department of Defense is examining several potential military uses for RLVs, including reconnaissance, satellite servicing, global strike, global transport, space control, and spacelift missions.[23]

If the U.S. truly intends to lead the world in space accomplishments and capabilities, it is inevitable that RLVs will be a central element of the U.S. national space strategy. It is therefore mutually beneficial for the United States to promote partnering relationship with industry in technology programs for RLVs. This discussion turns to a review of concepts and programs for RLVs.

Historical Background

The idea of RLVs is certainly not new. In the past, numerous technology programs for RLVs were pursued at varying levels of activity. In the late 1950s the DynaSoar (X-20) was followed by the Space Shuttle in the early 1970s, theNational Aerospace Plane (X-30) in the 1980s, and the Delta Clipper program in the 1990s.[24]

The history of the Space Shuttle program is particularly interesting. While the Space Shuttle is an effective vehicle, it is not efficient. It also holds the distinction of being the most expensive, and technically complex, project in the history of space exploration.[25] A contributing factor to the Space Shuttle's shortfalls in cost, complexity, and schedule was the decision to incorporate military requirements, in particular dramatic changes in the Space Shuttle design that were directed by the U.S. Air Force.[26] Initially, the USAF viewed the Space Shuttle as a replacement for expendable boosters, but the program expanded into a multi-purpose vehicle that would support the desire of the military services for manned spaceflight. The decision to add on-orbit checkout, re-supply, and the retrieval and repair of satellites, as well as requirements for surveillance and national reconnaissance programs, all affected the design of the Space Shuttle.[27] As the requirements advocate for the DoD, the U.S. Air Force guided the military performance requirements, including the payload size, weight, and orbital capabilities of the Shuttle. One telling example is the water-recoverable solid rocket boosters that were advocated by the U.S. Air Force. The final solid rocket booster design evolved from an Air Force 1960s development program, which lowered overall development costs by approximately $400 million, but more than doubled the operational costs to $10.5 million per mission.[28]

NASA's workhorse for nearly two decades, the Space Shuttle is perhaps the most familiar example of a "reusable" launch vehicle and is the only operational RLV today. For the foreseeable future, the primary mission of the Space Shuttle will be to haul astronauts and cargo to the International Space Station during its construction and initial operation through the year 2012. After the space station becomes fully operational, the Space Shuttle's future is uncertain, but it could still be flying in 2025.[29] At that point, the United States will need either a refurbished Space Shuttle or a new RLV to re-supply the space station.[30]

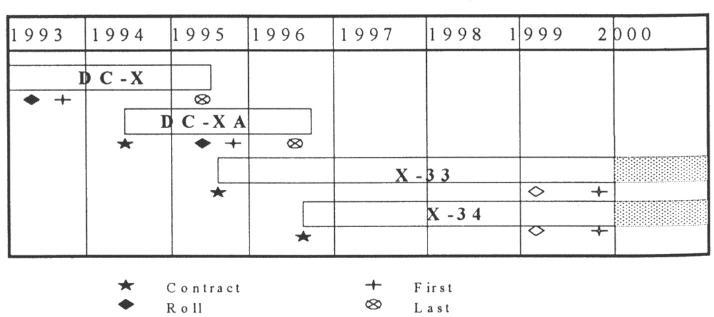
The concept of reusability is attractive because it reduces the cost of placing objects in orbit. To reduce costs requires vehicles that are reusable and have sturdy, yet lightweight components. The traditional method of increasing the amount of payload that can be put into orbit is to discard unneeded weight, often through the use of multiple stages. For example, after the Space Shuttle jettisons its two solid rocket motors, it recovers, refurbishes, and reuses these motors, but this is an expensive approach to reusability.[31]

The two other approaches that are favored by developers today are to use single-stage and two-stage to orbit vehicles. The single-stage to orbit vehicle is reusable because the engine and structure are so lightweight that it reduces the required quantities of propellant. The two-stage to orbit approach optimizes the first stage for atmospheric operations, while the second stage is optimized for operations that are at the upper reaches of the atmosphere or in space.

Reusable Launch Vehicles Recent History and Current Programs

The U.S. government has been investing in RLVs for decades, and continues to do so. The U.S. Air Force spent approximately $115 million on studies for RLVs between 1992 and 1997.[32] During this period, NASA's investment in RLVs was more than $ 1 billion, excluding the cost of the Space Shuttle. The majority of these funds were spent on programs and concepts that evolved from the Delta Clipper program, which is still in various stages of development. These programs and concepts include NASA's X-33 and X-34 (see Figure 1 for a timeline for these concepts and programs).

Figure 1. Reusable Launch Vehicle Concepts/Programs Timeline [33]



Delta Clipper Experimental (DC-X). The DC-X began as a private initiative that was funded by the Strategic Defense Initiative Organization, and managed by the U.S. Air Force Phillips Laboratory at Kirtland Air Force Base in Albuquerque, New Mexico.[34] McDonnell Douglas built the DC-X in the early 1990s as a one-third scale model for a conceptual single-stage to orbit vehicle. The eight DC-X test flights, which occurred from August 1993 to July 1995, lasted from 59 to 136 seconds and reached an altitude of 8200 feet. The DC-X demonstrated the ability to integrate critical subsystems for future RLVs with capabilities for sub-orbital or orbital operations.[35] The DC-X was instrumental in demonstrating that it is possible to develop vehicles that involve relatively low-cost operations, and that RLVs can be operable and supportable.[36]

Delta Clipper Experimental Advanced (DC-XA). The DC-XA was the DC-X modified for NASA and DoD under the Reusable Launch Vehicle Program. The major objectives of this program were to test advanced composite cryogenic tanks, improved reaction control systems, and other improvements to enhance its operability. The first flight of the DC-XA occurred in May 1996, lasted 62 seconds, and reached an altitude of 800 feet. The DC-XA hardware, support equipment, and crew demonstrated the ability to conduct a nine-hour turnaround between the second and third flights.[37] The third flight lasted 142 seconds and reached 10,300 feet in altitude. The DC-XA successfiully completed three test flights before human error on the fourth flight resulted in damage so severe that it has not flown since July 1996.[38] Perhaps the most significant contribution of the DC-XA program was to demonstrate the technologies and system design characteristics that enable quick-turnaround operations.

NASA X-33. The X-33 is a NASA-Lockheed Martin program that is designed to demonstrate the "aircraft like" operational aspects of RLVs. The federal government will fund $941 million, while Lockheed Martin will invest another nearly $300 million.[39] The X-33 plans to use a longer, shallower re-entry profile than the Space Shuttle to reduce re-entry heating.[40] The X-33 will be unmanned, take-off vertically, and land like an airplane. Fifteen test flights, which are planned to begin in late 1999, are designed to reach altitudes of 60 miles and speeds of Mach 15.[41] The goal of the program is to reduce business and technical risks, and thereby enable a cost-effective single-stage to orbit rocket system that eventually may replace the Space Shuttle. The goal is to reduce launch costs from approximately $10,000 to $1,000 per pound for low Earth orbit.[42]

NASA X-34. The X-34 is a NASA program conducted with the Orbital Sciences Corporation that seeks to design, develop, and test "key technologies" for integration in a reusable launch vehicle. The X-34 will use a single-engine rocket in an airplane-like vehicle that has short wings and small tail surface.[43] The X-34 serves as a bridge between the Clipper Graham (DC-XA) and X-33 programs. The Orbital Sciences Corporation will build the vehicle, while the government will provide the engine. The technical objectives include 25 test flights within one-year, subsonic and hypersonic flight (Mach 8 at 250,000 feet) autonomous flight operations, the use of composites (structures, tanks, lines, ducts), and low cost avionics.[44]

USAF Space Operations Vehicle (SOV). The SOV is best understood as a military spaceplane. The SOV is an Air Force concept, and while no funded program currently exists, programs such as the X-33 could be the basis for the SOV.[45] The SOV is envisioned as a RLV that is based in the continental United States, exhibits "aircraft-like" operations, will launch directly into low Earth orbit, and perform a wide variety of military missions in either manned or unmanned configurations. These missions include reconnaissance, global strike, satellite servicing, space control, and spacelift.[46] The SOV payload could include a number of Space Maneuver Vehicles (see below), and specialty orbital transfer vehicles that are designed to transfer SOV payloads to higher orbits. One such concept currently under study is the Modular Insertion Stage that would be used to transfer payloads into medium earth and geostationary orbits.[47]

USAF Space Maneuver Vehicle (SMV). The SMV is a reusable orbital vehicle that deploys from an expendable launch vehicle or SOV, performs on-orbit missions, returns to Earth for refurbishment, and is prepared for another mission.[48] The SMV concept involves a reusable upper-stage that provides substantial on-orbit maneuver capabilities, and functions as a space-based platform for carrying and deploying a variety of payloads. After its return to Earth, the SMV can be loaded with different payloads and readied for its next mission. The Air Force is currently testing a 90 percent scale version of a SMV atmospheric drop test vehicle that is being built by Boeing and which is designated as the X-40A. The full-scale version should be capable of carrying 1200 pounds of payload after on orbit deployment from an SOV [49]

While the U.S. government is involved in several partnerships with contractors in RLV projects, such as the X-33 and X-34, commercial contractors and private industry are pursuing their own RLV concepts. The commercial space industry is anxious to reduce the cost of access to space as well as other potential business areas, including global commercial travel, global parcel delivery, and space tourism. See Table 1 for a list of active efforts to develop RLVs.

Many of these efforts, especially those that involve manned crews, are pursuing the $10 million "X" prize.[50] This privately financed prize, which was announced on May 18, 1996, is designed to stimulate the development of commercial space tourism. The first private effort that builds and flies a reusable spaceship carrying three people on a sub-orbital flight will win a $10 million prize.[51] Two other prizes have been announced for $250,000 and $50,000, which are known as the "Cheap Access to Space" prizes. The $250,000 prize will go to the first group who can place 4.4 pounds in a 120 mile orbit by November 8, 2000, while the $50,000 prize will go to the first group that lofts a 4.4 pound payload to an altitude of at least 74 miles. The primary criterion, which is that the rocket must be "privately designed, developed, and built," is intended to spark creative approaches for low-cost access to space. [52]

Table 1 Private Reusable Launch Vehicle Efforts [53]

Company	Vehicle	Design	Crewed	Test Flight
Kistler	K-1	2-Stage Vertical Takeoff with Parachute Return	No	Mid 2000
Rotary	Roton	1-Stage Vertical Takeoff & Landing	Yes (2)	Late 1999
Kelly	Eclipse Astroliner	2-Stage Horizontal Takeoff & Landing	Yes(1)	?
Pioneer	Pathfinder	2-Stage Horizontal Takeoff & Landing	Yes (1)	2000
Space Access	Aerospace	2-Stage Ramjet Horizontal Takeoff and Landing	No	2001
Rutan	Proteus	2-Stage Horizontal Takeoff & Landing	Yes (3)	Stage 1 flew Aug 1998
Advent	Mayflower	1-Stage suborbital, water launch and landing	Yes (7)	?
Vela Techno-logy	SpaceCruiser	1-Stage suborbital Horizontal Takeoff and Landing	Yes (8)	2001
Lone Star Space Access	Cosmos Mariner	1-Stage suborbital Horizontal Takeoff and Landing	Yes (3)	?
Lockheed Martin	VentureStar	1-Stage Orbital Vertical Takeoff and Horizontal Landing	No	2001

Source: Author.

Among private RLV ventures, Kistler plans to have its K-1 RLV ready by mid 2000. K-l could be poised to capture a substantial share of the market for launching small communication satellites because it would be the lowest cost provider of space lift. The firm estimates that the cost will be $17 million per launch. To put that price in perspective, to orbit a similar sized payload today using the Delta II booster would cost approximately $55 million.[54] Kistler recently signed a contract with Space Systems/Loral for 10 1aunches of Globalstar satellites after the turn of the century.[55]

Kelly's Eclipse Astroliner also has an agreement for launch services. Motorola selected Eclipse Astroliner to launch 10 replacement satellites for the Iridium mobile satellite communications program, with a total price of reportedly $89 million.[56] Eclipse Astroliner is sized for small to medium class payloads into low polar or equatorial orbits. It is estimated that the market for this payload service will be $8 billion annually starting in 2002.[57]

Another unique concept is Pioneer's Pathfinder, which involves aerial fueling. The Pathfinder approach, which evolved from the "Black Horse" concepts in the U.S. Air Force *Spacecast 2020* study, uses conventional jet engines to carry the payload and Rocket Propellant-l, which is a highly-refined form of kerosene. At 25,000 feet, the Pathfinder rendezvous with a tanker to load 130,000 pounds of liquid oxygen, which is consumed by a single RD-120 rocket engine that propels the Pathfinder on a sub-orbital trajectory of 80 miles where the payload is released. The payload is placed in orbit using a small but as-yet undetermined upper-stage, and the Pathfinder lands downrange using conventional jet engines.[58]

Rotary's Roton is an unusual design that launches vertically like a conventional rocket, but deploys rotors after reentry to land vertically in the same fashion as an auto-rotating helicopter. Roton is 53 feet high, 18 feet in diameter, and has a payload capacity of 7,000 pounds. The Roton is designed to service the low-earth orbit communications spacecraft market. Target launch costs are $7 million per launch with first operations planned to occur within the next five years. [59]

Another commercial concept is the VentureStar, which is Lockheed Martin's full-scale version of the NASA X-33. VentureStar targets the traditional spacelift mission with the objective of $1,000-$2,000 per pound of payload, seven-day turnaround, and extremely high reliability.[60] VentureStar will compete with other RLV projects.

The foreign firms are also interested in RLVs. The European Space Agency, with Great Britain in the lead, initiated the Skylon program in the 1980s. This program investigated the viability of developing cheap and easy access to space without the need for the traditional infrastructure or large ground crews. The program centered on a 270-foot long space plane that was capable of carrying 20,000 pounds into low Earth orbit.[61] A number of European states continue to have interest in RLVs.

Recent study efforts of the European Space Agency included the Ascender project, which is a sub-orbital airplane that is suitable for carrying passengers. It takes off from an ordinary airfield using a turbofan engine, which at 26,000 feet starts a rocket engine and climbs vertically at Mach 2.8 to reach a maximum altitude of over 325,000 feet. Ascender plans to carry two crew and two passengers, making it a possible European entrant for the X-Prize. Follow-on plans include a fully orbital spaceplane that is suitable for small satellite delivery to orbit, which is called the Spacecab, and is designed to be 100 times less expensive than the Space Shuttle. An even larger design, called the Spacebus, is designed to carry 50 people to and from orbit or fly passengers from Europe to Australia in 75 minutes. [62]

The Japanese government has actively pursued the research and development of a space plane concept called the HOPE-X, which is an unmanned winged space vehicle. This technology demonstrator will be launched from a Japanese H-IIA rocket. HOPE-X is scheduled for its first flight in 2000. To date, the Japanese have conducted several technology demonstration flights and experiments in support of HOPE-X. In February 1994, they conducted an orbital recovery experiment, in February 1996 completed a hypersonic flight experiment, and conducted automated landing flight experiments in July-August of 1997.[63] The ultimate purpose of HOPE-X remains unclear, but it demonstrates that Japan remains active in RLV research and development.

There is also interest among civil firms in RLV technology. Lawrence Livermore National Laboratory engineers proposed a concept for spacelift that is called the HyperSoar, which is an "aircraft-like" vehicle that could serve as the first stage of a two-stage launch system. HyperSoar uses a rocket-based combined-cycle engine that is used throughout the flight. HyperSoar uses a cyclic trajectory (the engine cycles on and off producing an oscillating altitude) ranging from 115,000-200,000 feet and achieves speeds of Mach 10-12. To place a satellite in orbit, HyperSoar will use an upper stage. [64]

In summary, there are continuing and substantial efforts on the part of governments and private firms to develop RLVs. While it is still too early to pick the likely "winners," the most viable contenders at this point appear to be partnerships between the U.S. Government and Lockheed-Martin, Boeing, and Orbital Sciences Corporation. The next critical step is the development and integration of technology into practical vehicles.

Technical Challenges

The most significant technical challenges to developing RLVs are operability and reliability. To be truly reusable, the launch system must be highly functional with minimal servicing. High operability must extend to the launch vehicle, its components, and several ground facilities, while minimal servicing means that refueling occurs after the flights. To operate from a wide variety of commercial spaceports, rather than remote government test ranges, the launch system must be as reliable as commercial airliners. Of the numerous technical challenges to achieving the required operability and reliability, the principal are thermal protection systems, reusable propulsion systems, non-toxic propellants, lightweight structures and components, and integrated launch vehicle health monitoring systems.[65]

Thermal protection systems are essential if vehicles are to survive reentering the earth's atmosphere. Friction between the atmosphere and the spacecraft traveling at high speeds generates extreme heat that will: consume unprotected vehicles. For near earth orbits, the reentry velocity closely approximates the orbital velocity. For example, the Friendship 7 Mercury capsule piloted by John Glenn achieved a maximum speed of 25,700 feet per second at an altitude of 100 statute miles.[66] Exact values are contingent upon a variety of factors, including the reentry angle and ballistic coefficient of reentering object, but typical surface temperatures on the vehicle reach 3000 degrees Fahrenheit and the surrounding air can reach temperatures of 20,000 degrees Fahrenheit for steep reentry angles.[67] To put this in perspective, aluminum melts at 1,220 degrees Fahrenheit, low carbon steel at 2,760 degrees Fahrenheit and Titanium at 3,135 degrees Fahrenheit.[68] The Space Shuttle's thermal protection tiles have been a problem because moisture or any physical impact (such as bumping) can easily damage the tiles, which must be inspected, repaired, and replaced by hand after each Space Shuttle flight. For true operability, the vehicle must have a highly damage-resistant thermal protection system that does not require servicing between flights. One intriguing possibility under study is "hot metal," or titanium-based

derivatives, which can survive the extreme heat of reentry without thermal protection.[69]

Reusable propulsion systems are vital to the success of RLVs, but significant research and development is needed in this area. Currently, only the Shuttle main engine and a few Russian rocket engines are capable of supplying the required thrust. However, the Shuttle engines are far too complex and expensive for commercial users. They require extensive, time-consuming, and expensive work after each flight. The Russian engines are not sufficiently reusable because each engine is designed for only 10 flights. There are no engines currently in developments that are suitable for RLVs. While Rocketdyne has an engine design that may work, this conceptual design is not yet in development.[70] The lack of an existing rocket engine with the desired operability and reliability characteristics represents an enormous technical challenge for the development of RLVs. This technical roadblock looms is quite significant given that developing a new engine can involve hundreds of millions of dollars, which very few private companies can afford.

Associated with the need for a suitable rocket engine is the type of propellant used by that engine and other on-board power generating systems. Current propellants, usually chosen for their high energy content per pound, are highly toxic. Non-toxic propellants are highly desirable because they are far easier and safer to handle, store, and use. Two sets of propellants, liquid oxygen with liquid hydrogen for fuel, and liquid oxygen and JP-8 as fuel, are emerging as the preferred options for RLVs. The advantage is that these combinations are relatively inexpensive, plentiful, easy to manufacture, and environmentally sound. However, with the exception of JP-8, the propellants are cryogenic and therefore require special handling and storage. Additionally, they are extremely flammable and the quantities necessary to achieve orbit are so large that on-board storage tanks will be required. The challenge is to minimize the weight of these large, specialized storage-tanks because this will allow the vehicie to carry more payload into orbit, which is essential to the success of RLVs. The DC-XA program demonstrated the utility of lightweight composite cryogenic tanks in 1996, and NASA's X-34 program will test advanced composites in tanks and other key components.[71] Another issue related to weight management is the ability to replace the hydraulic components that move control surfaces with electromechanical actuators.

The drive toward simplified maintenance will depend on integrated systems for monitoring the health of the vehicle. Current maintenance practices, such as those used on the Space Shuttle, require a labor-intensive and expensive process of inspection, testing, re-qualification and replacement of components after each launch. RLVs will need systems to monitor and assess the status of vehicle components, predict which subsystems are degrading, and recommend maintenance. This type of a monitoring system is essential to keeping costs low while achieving high operability and reliability. To address the variety of technical challenges, NASA, the U.S. Air Force Space Command, and the Air Force Research Laboratory formally agreed to combine and coordinate their RLV efforts in October 1997. Specifically, the Air Force will identify and fund military-unique technologies for RLVs and develop specialized payloads, while NASA will lead the development of technology demonstration vehicles.[72]

NASA is pursuing a number of technical programs for the development of RLVs. NASA formed the Space Transportation Programs office in the mid-1990s to "develop and demonstrate key, critical technologies which will significantly reduce the cost of space transportation and enable future space missions."[73] These programs include the previously mentioned X-33 and Future-X as well as the Advanced Space Transportation Program Boeing was selected in December 1998 as the contractor for the next Future-X technology demonstrator, which is known as the Advanced Technology Vehicle. This Future-X program involves a cost-sharing arrangement in which each partner provides $150 million over four years.

Future-X is aimed at increasing U.S. global competitiveness by reducing the cost of getting to space. [74] To accomplish this, the Future-X program includes a core technology development effort which focuses on low-cost space transportation, Pathfinder vehicles, which is a series of approximately $100 million efforts that require flight tests to validate their technologies; and Trailblazer vehicles, which are integrated flight demonstration vehicles to validate technologies, operations, performance, and cost.[75] Under this approach, the X-34 is essentially the first Pathfinder program and the X-33 is the first Trailblazer.[76] This NASA research programs consists of 29 specific demonstrations in the areas of on-board propulsion, onboard intelligence planning system for autonomous abort landings, integrated-vehicle health-management system, thermal protection systems, propulsion technologies, and advanced cryogenic upper stages.

The Advanced Space Transportation Program is pursuing several technology areas that are directly applicable to RLVs, including airframes, lightweight structures, thermal protection systems, automated checkout and health monitoring, and long-life propulsion components. Through the Future-X project, NASA is pursuing technologies that are beneficial to both the military and commercial industry. In particular, the Air Force identified a number of specific technological and operational areas in the Future-X that support specific Air Force requirements.[78] At present, it appears that all of the essential technology efforts for developing RLVs are underway to some extent. The principal concern at this stage is that the pace of technology efforts may not be sufficiently intense to support the development of critical technologies, particularly in the area of propulsion.[79] NASA, the DoD, and industry are sharing the workload and cost of these technology efforts.

Information gained from the NASA-led development efforts in these critical technology areas is being shared with industry and the Department of Defense NASA also has organized a comprehensive research program that is consistent with the National Space Transportation Policy and the development of RLVs.[80] The NASA-led Space Transportation Architecture Study will draw heavily from these technology efforts and ultimately influence how NASA funds the development of future spacelift. [81]

Economic Considerations

A reasonable projection is that commercial firms will continue to invest heavily in space technology, products, services, and spacelift. Given the competitive marketplace, the commercial space industry in the United States is likely to succeed in the development of spacelift in areas that are of interest to the military.

The development of RLVs is an expensive proposition. Some have estimated that the development costs will be equivalent to developing a new commercial airliner, which in the case of the Boeing 777 aircraft exceeded $5 billion dollars.[82] While private investments of this magnitude do occur, private investors are likely to pursue a number of less-costly alternatives to RLVs because the development costs will be so expensive that no one company will pursue it alone.[83] Nor is it likely that the U.S. government can be relied upon to fully fund the development of RLVs. One approach is to outsource the development of RLVs[84]. While it is by no means assured that spacelift is a vital wartime function that should be outsourced, the Department of Defense should expect that there will be increasing pressure to outsource all scheduled space launches to U.S. commercial firms.

The Evolved Expendable Launch Vehicle program, which follows the current expendable launch vehicles, appears to be a step in this direction.

Legal and Policy Issues

The essence of U.S. national space policy is to preserve space for all humanity to use for peaceful purposes, to ensure that space systems are sovereign property, and serve the rights of all nations to safe passage in space that is free of interference.[85] In addition to national policy, a number of international treaties, agreements, and domestic laws affect U.S. space activities. In the case of RLVs, states are responsible for governmental and private space activities, launching sites are liable for damage caused by space objects they launch, and parties must register objects that they launch into space.[86] U.S. policy is that NASA is responsible for manned space activities, and ensures that NASA will dominate any manned space government-sponsored research and development. Accordingly, the U.S. National Space Transportation policy that was formalized on August 5, 1994 assigned roles for NASA and the US Air Force regarding reusable launch systems.[87]

U.S. policy also mandates that NASA will work with the private sector on reusable launch systems, and specifically, that NASA and private sector teams will conduct technology demonstration programs that will support informed decisions about RLVs by the end of the decade. The DoD, which represents the defense and intelligence sectors, is charged with ensuring that an appropriate launch system capability exists to meet national security needs. To accomplish this, DoD needs to maintain the nation's present expendable launch capability as well as to prepare for future launch needs. DoD is interested in reusable launch systems because these may potentially reduce costs and increase access to space.[88]

The U.S. Congress has influenced how both the U.S. government and U.S. companies have pursued the development of space technologies. Some of the most pertinent legislation deals with commercializing space, including the Commercial Space Launch Act of 1984 and the Commercial Space Act of 1998. The main thrust of the legislation is to encourage the development of a commercial space industry. This legislation includes provisions for licensing commercial launch and reentry vehicles, commercial use of excess government launch facilities, prohibition of government competition with commercial entities, and the requirement for the Federal government to procure commercial space transportation services.[89]

Threat Considerations

A variety of threats exist to the uninterrupted use and exploitation of space. These threats range from man-made such as space debris and hostile acts, to natural aspects of the harsh environment of space, including meteor showers. The threats addressed here are man-made, which may directly affect the planned use of RLVs by the U.S. military, commercial companies, and private citizens.

The "military threat" consists of an adversary's direct military action against U.S. satellites, their communication links, and the potential for an adversary to use commercial space data such as imagery against the United States Military attacks on ground facilities supporting space programs, while potentially effective, are not addressed in this study.

The types of responses the United States might want to make generally fall into the two categories: negating and protecting. Negating can include actions that disrupt, degrade, deny, or even destroy an adversary's space capabilities. Protecting can incorporate a wide range of activity, but is the essence of space control—defined as "Operations to assure the friendly use of the space environment while denying its use to the enemy."[90] Several potential adversaries currently possess the means to disrupt or deny satellite communications, as well as data and command links. It is conceivable that states could initiate disrupt or deny actions against both commercial leased and dedicated military satellite communications.[91]

The existing direct-attack military threat against our assets has been principally monolithic, consisting of the Soviet anti-satellite capability of both kinetic kill and directed energy applications. In 1997, Russia stated that it had developed but abandoned its anti-satellite capability, but the DoD disputes this position. Recent reports suggest that China now has the technology to construct ground-based lasers that are capable of damaging some spacecraft sensors.[92] Incidentally, the commercial industry remains unconvinced and unconcerned about potential threats to their systems. They have declined to adopt protective or defensive measures in their vehicles even after the U.S. military outlined the threat [93] Some have used the analogy that commercial airlines do not carry chaff and flares for self-defense, but rely on the military to ensure their freedom to conduct commerce. To the commercial community, spacecraft design involves significant business decisions, and no one has made a successful case that they must change.

Another threat to the U.S. is the possible use of commercially available products by an adversary to gain intelligence that the U.S. would rather they not have. An example is satellite imagery about U.S. force dispositions. Commercial space systems will continue to increase capabilities and in some areas may eventually rival specialized national intelligence assets. These specialized products will be readily available to any nation or individual with sufficient funds. As an example, a Colorado-based company, Space Imaging, is poised to offer "satellite-quality spy pictures" (three-foot resolution) for sale, to anyone who provides them with coordinates. The operational significance of three-foot resolution is substantial. To put three-foot resolution in perspective, the recently unclassified National Reconnaissance Office CORONA satellite images collected between 1960 and 1972 achieved a ground resolution of only six feet.[94] Aside from the ability to monitor troop concentrations, aircraft on runways, massed vehicle formations etc., three-foot imagery provides substantial capabilities. [95]

The most serious threat to U.S. national security may be the economic threat of losing the race to develop viable RLVs. The company or nation that achieves low cost, routine, and reliable spacelift on the order of $1000 per pound to low-earth orbit will dominate the international spacelift market. When a viable RLV emerges, current and planned expendable launch vehicles may well become obsolete. To meet the U.S. National Security Strategy of "maintaining leadership in space," the U.S. must be the first nation to develop a viable reusable launch vehicle.

Table 2. Reusable Launch Vehicle Development

Category	Environmental Aspects
Activity Forecast	- Today 75% of satellite launches worldwide are commercial - By 2007, another 1,715 satellites are forecast for launch, of which only 129 are Western military satellites - Over the next 20 years, at least 9 countries will manufacture a total of 1,700 expendable launch vehicles in 28 distinct types - A high speed (space vehicle) point to point parcel delivery market may be feasible at a price of $500 pound
Technical	- Most significant technological challenges to developing reusable launch vehicles are operability and reliability - Specific challenges include thermal protection, reusable propulsion, user-friendly propellants, and vehicle health monitoring systems
Economic	- Development of commercially viable reusable launch vehicles will be so expensive as to prohibit one private company from pursuing it alone. U.S. government financial participation is required.

Legal/Policy	- Domestic policy and international agreements govern U.S. space activity. Some major national policy elements are:
	  - Space is for all humanity and for peaceful purposes
	  - Space systems are sovereign property
	  - All nations have a right to free safe space passage
	  - NASA is lead for all manned space activity
	  - DoD is to ensure launch capabilities meet national security needs
	- Commercial Space Act 1998 encourages development of a commercial space industry

Threats	- Threats exist, both natural and man-made, to the continued uninterrupted use and exploitation of space

This section has reviewed the environment within which reusable launch vehicles are being developed and Table 2 summarizes the major points. Given that space will be a booming business for the next twenty years, RLVs can arguably play a large role in realizing the potential of the space growth market for both the U.S. government and commercial community. The next section assesses the utility of potential RLVs for military missions and commercial applications.

III. Analysis of Reusable Launch Vehicle Missions

Table 3. Reusable Launch Vehicle Missions andApplications Assessed

This section examines RLV missions and applications.

Military Missions	Commercial Applications
Reconnaissance – supplement on-orbit intelligence, surveillance, and reconnaissance systems **Global Strike** – bring precision combat power to bear directly against an enemy's war-sustaining capabilities or will to fight **Satellite Servicing** – provide means to refuel, upgrade, reposition or recover space assets **Global Transport*** – transport troops or material rapidly around the globe to prepared sites **Space Control** – conduct counterspace actions which could temporarily disrupt hostile space assets while protecting our space-based assets, both military and commercial **Spacelift** – provide rapid response to complement dedicated spacelift assets at low cost	**Satellite Servicing** – provide means to refuel, upgrade, reposition or recover space assets. **Global Transport** – transport people or cargo rapidly around the globe to prepared sites **Spacelift** - provide routine, reliable, cost-effective (goal is one tenth or less the current cost) and user-friendly scheduled access to space for deploying satellites, re-supplying space stations, or other activities such as conducting experiments and manufacturing. **Tourism** – provide round trip, routine and reliable access to space for anyone with $20,000.

* Global Transport is no longer a primary military mission as envisioned by Air Force Space Command

Earlier sections in this study focused on the fact that space is important to U.S. national security for both military and economic reasons. It also argued that global demand for space products and services continues to grow rapidly, that the U.S. must reduce spacelift costs, and that the best way to reduce the costs of spacelift is to develop RLVs.

Military Utility of Reusable Launch Vehicles

The U.S. Air Force vision for RLVs rests on the Space Operations Vehicle (SOV) and its complementary "upper-stage," the Space Maneuver Vehicle (SMV). The SOV is an Air Force concept for a reusable launch vehicle, which is also known as "military spaceplane," but as of this writing is not a funded program. The Air Force plans the SOV/SMV combination to be the U.S. first space superiority weapon system.[96]

Current U S. Air Force thinking on the military utility of RLVs is outlined in the Air Force Space Command's Concept of Operations for the Phase I Space Operations Vehicle. This document describes how the Air Force Space Command believes that the SOV should be deployed, employed, and operated. The Air Force Space Command suggests that RLVs should augment, rather than replace, conventional air-breathing aircraft for the traditional missions of air superiority, strategic bombing, mobility, search and rescue, and close air support. The U. S. Air Force of the future will most likely be called upon to enforce no-fly zones or perform other missions that require a significant inventory of diverse traditional aircraft, including bomber, transport, command and control, fighter, attack, surveillance, and tanker aircraft. In this way, a military RLV will become an integral part of the mix of aerospace vehicles. This new force will require considerable analysis if we are to achieve an optimal balance of vehicles, support facilities, and manning.

The Air Force Space Command's Concept of Operations for the Phase I SOV presents a survey of potential missions for a military SOV. This concept of operations emphasizes the multi-mission nature of the SOV, which strongly suggests that the total utility is greater than the "sum of utilities" of separate missions. While officers at the Air Force Space Command suggest that this broad synergy should be the basis for pursuing the SOV, this concept does not lend itself to objective assessment.

The Concept of Operations document does not prioritize missions, which means that this study of the utility of the SOV for multiple missions is essentially a compilation of individual missions.

A related issue is whether RLVs should be manned or unmanned. As the Concept of Operations for the Phase I SOV System notes, "It will be flown manned or unmanned with the type of mission determining the need for an on-board crew."[97] It addresses the ideas of flight training for take-off, landing, en-route navigation, and instrument flight rules, and suggests the possible requirement. For a companion aircraft that is modified to emulate the sov.[98] This clearly implies the SOV will be piloted. While officials in the U.S. Air Force Space Command confirm the possibility that SOVs may be piloted, the collective judgment is that unpiloted SOVs are the preferable option. The only mission that might require manning are those that require human skills, as exemplified by servicing satellites in orbit. In that case, the crew would serve as technicians rather than pilots. This preference for unpiloted vehicles is gaining technical support from in-progress utility studies, but this view is not unanimous. Powerful constituencies in the Air Force remain convinced that delivering weapons must be manned. While the Concept of Operations does not recommend that any specific military mission should be manned, the question of manned versus unmanned remains unresolved. Accordingly, this study will proceed with the assumption that the military hopes to develop a RLVs that are manned for global strike and satellite servicing missions. This section evaluates the six military missions that are under consideration for reusable launch vehicles based on the ideas outlined in the document published by the U.S. Air Force Space Command.

Reconnaissance Mission. The objective of the reconnaissance mission is to supplement intelligence, surveillance, and reconnaissance satellite systems, which includes imagery and signal information, among other capabilities. The objective is to provide the operational community with complete theater coverage. Many observers believe that today's reconnaissance systems do not have global coverage and that there are significant time lags between the time the data is requested and the time the data is provided to the consumer.[99] A Space Maneuver Vehicle (SMV) with reconnaissance payloads could supplement existing reconnaissance systems by providing more focused coverage because it has the ability to respond rapidly as well as maneuver.[100]

The essential attributes for a militarily responsive RLV for the reconnaissance mission include rapid response, small to medium payload capacity, and high maneuverability.[101] Each of these attributes affects the design of RLVs. This study shows that the military objectives will not be achieved by standard payload interfaces because rapid response capability and maneuverability directly and fundamentally affect the design of reusable launch vehicles.

A prudent assumption is that the U S. technical community will be able to solve the key issues that are associated with creating viable RLVs, and that the military will be able to use these vehicles to deploy smaller reconnaissance satellites. While this study does not address the cost of developing reusable launch vehicles, the SMV reconnaissance mission faces a number of challenges, including the organization of the intelligence community, the philosophy of disseminating reconnaissance information, the equipment available to the operational force, and the time it takes to get information to the right organizations.

The current intelligence structure directs reconnaissance data into areas of expertise depending upon the data collected. Data is analyzed, fused and forwarded to users and the chain of command as appropriate. A SMV-deployed sensor that collects high-quality reconnaissance data and delivers it directly to a consumer is different from the existing and planned system for disseminating intelligence information. A direct downlink of reconnaissance data is strongly advocated by some consumers, and strongly resisted by others. A significant debate, which is not limited to SOV's, is the merits of direct downlink versus centralized processing.

A related debate coupled to direct downlink is the issue of the equipment that the consumer used to receive intelligence information. The Department of Defense's *Joint Vision 2010,* which is the operational framework for U.S military forces, emphasizes interoperability.[102] Plans to provide direct downlink intelligence, surveillance, and reconnaissance data must be consistent with the vision of interoperability among all U.S. forces.

A challenging barrier to reconnaissance with RLVs is the operational implication of improving national collection systems and timelines. One of the major reasons for developing a reconnaissance mission for reusable lauch vehicles is to improve the timeliness of intelligence information for the operational community. In the past, there were many reasons for delay, but

substantial progress has been made in national intelligence collection and delivery timelines, and further improvements are planned.[103] When the U.S. is at war or in a crisis, all national resources, including national intelligence assets, will be available to the regional Commander in Chief (CINC). Most recently, the combat experience in December 1998 against Iraq raises questions about the need for major improvements in combat intelligence support from space-based reconnaissance systems. While intelligence timeliness and products can be improved, it is clear that national intelligence data can provide timely support to the combatant commanders.

If weather precludes national systems collecting data, other space assets are not likely to perform any better. In the case of being out of position, this will be resolved in some finite time given the geographic location of the target and the orbits of national assets. It is likely that in some instances national assets will be able to image the target before a satellite that is deployed by a RLV. If the RLV could deploy numerous reconnaissance sensors, this could improve the overall coverage and revisit rate for specific areas. The associated "cost," however, is an increased demand for command and control of these newly deployed assets. Furthermore, command and control challenges involve more than just traditional telemetry, tracking, and commanding, and include deciding who "owns," operates, and tasks these assets as well as who gives the launch command. None of these challenges are insurmountable, but they highlight the fact that implementing reconnaissance missions with RLVs is a formidable task.

One major hurdle to developing a reconnaissance capability with RLVs is that the regional CINC must define a requirement for this capability. While the regional CINCs have clearly articulated intelligence requirements, they also have substantial intelligence systems at their disposal. Their historical preference is for organic systems that are under their exclusive control. The fact that the CINCs will demand regular opportunities to train and deploy with the systems they will employ in war means that the concept of SOV-deployed reconnaissance satellites must include routine deployment and training with military forces.

In order for an SOV-deployed reconnaissance payload to outperform national assets, it must have a substantially greater capability.[104] It would require an inventory of reconnaissance satellites, the ability to place those assets on-orbit, and ensure that they can operate over the area of interest within eight hours. The key challenges are whether reconnaissance sensors

will be ready to launch on short notice and be capable of “instant on-orbit checkout.” At present, it takes about 70 workdays to prepare a military communication satellite for launch and over four months to check it out once it is on-orbit.[105] Additionally, competing with the timelines for national systems requires a “ready fleet” of RLVs. As a benchmark, the “Black Horse” RLV concept requires an annual budget of $100 million to operate and maintain eight RLVs.[106]

There are numerous alternatives to relying on SOV-deployed sensors to provide combat units with critical intelligence, surveillance, and reconnaissance data. Those alternatives include commercially available information, relying on national assets, and the use of Uninhabited Aerial Vehicles (UAVs). In the future, the proliferation of imagery systems by numerous commercial companies and nations virtually ensures that we will have regular access to global imagery. The proliferation and capabilities of these commercial systems will be so significant that many believe U.S. adversaries will be able to exploit these commercial products. If these commercially available products would be operationally significant to an adversary, it is likely that they could be operationally significant for U.S. forces.

The USAF acknowledges that commercial satellite imagery is rapidly becoming a key source of information for current USAF operations. As an example, commercial imagery is used to support mission planning, including the selection of landing and drop zones. The USAF uses commercially procured imagery today to meet regularly unfulfilled imagery requirements that are caused by gaps in coverage or competition for scarce national resources. The Air Force further predicts that the next generation of U.S. and foreign commercial satellites will provide a significant military value that is comparable to government sources.[107] While the military is unlikely to rely on commercial sources as the principal method for obtaining imagery, this remains a viable and inexpensive source that complements other capabilities, such as national reconnaissance and theater organic assets.

A comparison of the overall performance of an SOV-delivered reconnaissance satellite with an existing national capabilities raises questions about the advantages derived from SOV-deployed satellites. If one assumes that the two satellites have comparable capabilities in terms of sensor performance (which is not quite realistic), the satellite deployed by a RLV will still have limited access to the target area because it is in low-earth orbit.

While deploying additional satellites from RLVs will increase the coverage and provide the desired revisit rates (one example uses three sensors to provide coverage every 90 minutes),[108] the addition of each new satellite compounds the command and control problem. To achieve the ideal spacing of sensors requires substantial separation between the sensors. This requirement means that several RLVs missions will be necessary to deploy sensors in the proper orbits, or the use of extremely maneuverable upper stages for deploying the sensors from one RLV. Initially, the RLV could deploy the sensor over the area of interest at a specific time to achieve coverage on the first pass, but that will be short target for roughly one half day.

Uninhabited aerial vehicles (UAVs) may have several advantages over manned and high altitude/orbiting systems because they can function under cloud layers, are relatively inexpensive, and can be deployed rapidly.[109] The weather through some UAVs can fly may degrade the performance of an optical satellite, and there is no postulated operational concept for RLVs that can deploy the sensor to a theater before the deployed forces can launch UAVs. UAVs are not the solution in themselves, but working in conjunction with on-orbit assets and other theater reconnaissance assets, "UAVs clearly demonstrated their ability to complement other information systems, providing unprecedented views of the tactical battlefield for field commanders and operational level decision makers."[110]

This assessment of reconnaissance suggests that the military will benefit from the employment of RLVs. A second conclusion is that the reconnaissance mission is essentially the same as the traditional mission of spacelift in which the payloads are reconnaissance sensors. That being said, the reconnaissance mission does not provide a sufficiently compelling reason for the Department of Defense to start a major new program.

Global Strike Mission. The objective of global strike is to bring precision combat power to bear directly against an enemy's military capabilities or will to fight. RLVs launched from the United States have the potential to achieve orbit and deliver precision guided weapons to enemy targets on a global basis.[111] There are numerous advantages to this capability, including the ability to respond globally on a rapid basis, the ability to standoff yet still achieve precision effects, and the need for fewer forward-deployed U.S. units. Such a capability would be an integral part of a future Air Expeditionary Force because it would allow the United States to minimize

putting personnel at risk, respond to a crisis anywhere, and operate from bases in the United States. Nor would the United States have to worry about permission for the overflight of states.[112] Thus, the essential design characteristics for RLVs that are capable of global strike include rapid response, possibly manned/crewed vehicle, highly maneuverable system; and a payload capability of up to 20,000 pounds.[113]

Many of the concepts for delivering weapons focus on the Common Aero Vehicle, which is a maneuvering reentry vehicle that is carried by the SOV. The SOV releases the Common Aero Vehicle, which dispenses those weapons in the atmosphere. The concept is analogous to precision guided munitions that are carried by conventional aircraft. The Common Aero Vehicle has the necessary thermal protection, guidance, and maneuverability systems to deliver precision guided munitions to pre-determined release points, where it will achieve the desired accuracy of ten feet or less. Various studies suggest that a Common Aero Vehicle will weigh 2,250 pounds, of which 1,200 pounds will be the weapon payload.[114]

The primary challenge for the global strike mission is to achieve better cost and operational effectiveness in comparison with existing and planned weapon systems. While any meaningful examination of cost is beyond the scope of this study, a prudent assumption is that RLVs performing the global strike mission must be affordable.[115]

Another factor is the range of the RLV. As examples, the air-launched cruise missile, AGM-86B, has a range of 1,500-plus miles, the AGM-86Cs range is 600-plus miles.[116] The submarine or ship-launched land attack cruise missile, Tomahawk, has a nominal range of 1,000 miles.[117] These ranges allow U.S. forces to strike land targets worldwide without the need for the launch platform to violate a nation's sovereign territory, with few exceptions.

For these target exceptions, other strike options exist, such as penetrating specialty strike aircraft (e.g., B-2, F-22, F-117). The response times for cruise missiles launched by deployed forces are measured in hours, which is essentially the same as the response time that is postulated for RLVs performing global strikes.[118]

At present, air-launched cruise missiles and their B-52 host platforms are stationed in the CONUS. In 1991 and again in 1996, B-52s were launched from CONUS, and fired 48 cruise missiles against Iraq.[119]

The round trip was over 14,000 miles and took 35 hours, which required air war planners to launch the B-52s about 18 hours prior to the start of hostilities. Given the level of planning and coordination that is required for these attacks, a rapid response is desirable, but the time that it takes to deliver weapons is not the limiting factor in the execution of military options.

One final challenge for global strike with RLVs is their capacity. In the December 1998 combat action against Iraq, U.S. forces launched 425 cruise missiles.[120] If one assumes that RLVs carry ten Common Aero Vehicles, each of which carries one 1,000 pound precision guided munitions,[121] the ten weapons per sortie would be half the capacity of a B-52 bomber. This means that more than 42 sorties would be necessary to match the current delivery means. Assuming RLVs based in the continental United States are capable of one sortie per day for each vehicle,[122] and given a four-day campaign goal, a minimum fleet of ten vehicles is necessary. Given the training and maintenance to support a posture for major theater wars, a squadron of at least fifteen or more RLVs will be necessary for global strike missions.

The development of a military RLV may detract from U.S. national security if it drives other states to engage in an arms race.[123] Given the high cost of developing, procuring, and operating RLVs, it is unlikely that another nation will obtain an offensive capability with RLVs capability in the foreseeable future.[124] But other states may pursue countermeasures to RLVs in order to erode or nullify the U.S advantage. While it is a less likely response, other countries may develop their own “orbital or sub-orbital space bombers” in response to U.S. deployments, which could spur the weaponization of space.

One concept for global strike, which is known as HyperSoar, has a payload of 11,000 pounds, which is equal to roughly five weapons per sortie. The nature of global strike is fundamentally different from space launch because achieving orbit demands a different design than a strike vehicle in terms of payload, size, type of propulsion, heat dissipation, and landing concepts, among others.[125] Some within the military argue that RLVs for global strike should be manned and possess a rapid response capability.[126] This supports the case that military missions and commercial applications require fundamentally different types of RLVs.

There are several alternatives to conducting global strikes with RLVs, including cruise missiles and specialized strike aircraft, but each of these alternatives involves substantial “costs” that are well-known in the defense community.

However, significant national policy decisions will have to be involved before the United States employs weapons from space. As a practical matter, it is highly unlikely that the United States will be the first to use weapons in space.[127] While some argue that using RLVs is escalatory because it constitutes an attack from space, proponents of RLVs argue that the precedent for using weapons is derived from inter-continental ballistic missiles (ICBMs), which is another form of surface-effect weapons.[128] ICBMs have not been employed in war, and when Iraq during the 1991 Persian Gulf War used short-range ballistic missiles, it strengthened the resolve of the coalition partners. For senior policy makers, weapons launched from RLVs represent a substantial change in the conduct of war. Wargaming experience shows a strong reluctance by the National Command Authority to initiate space warfare because by the time the National Command Authority authorizes the use of weapons from space, conventional cruise missiles could have been used.[129] As technology historically increases the distance between the human and the weapon, the use of a manned platform in space for launching conventional weapons is consistent with the pattern of technological progress. [130]

Some advocates of global strike argue that these missions should be manned because this will preserve positive human control over weapons.[131] But as a high value item that it will never be procured in large numbers, policy-makers will employ this technology only in the most extreme circumstances. While a global strike SOV may be survivable because it never penetrates hostile airspace and is not vulnerable to conventional air defenses, this system will be expensive, procured in small numbers, and reserved for use in special circumstances. Even if one argues that RLVs will be reserved for serious circumstances, there is still a limit to how many of these systems the United States can afford.[132]

The development of a military RLV that can perform the global strike mission is the next logical step because this capability would strengthen the ability of the U.S. Air Force to strike on a global basis. This would be a highly desirable option because the U.S. military could project power globally without the constraints of 35-hour B-52 missions. It also might reduce the size of conventional aerospace forces. For instance, if a fleet of RLVs could accomplish 50 percent of the required precision strikes, fewer F-16s, F-117s, Fl5Es would be needed, which would further reduce the need for in-theater tankers as well as maintenance and support personnel.

It is unclear whether the U.S. Air Force would want to eliminate some of its F-16, F-I5E, and F-117 squadrons to fund a global strike RLV. Furthermore, the Navy would wonder whether a sufficient number of U.S. Air Force RLVs would be so capable of global strike that it negates the rationale for aircraft carriers. Following World War II, during the budget battles among the services, the Air Force argued that the arrival of nuclear weapons delivered by long-range bombers made aircraft carriers obsolete.[133]

The investment required for global strike RLVs is estimated to be in the range of $750 million and $1 billion per RLV for manufacturing costs alone.[134] When ground facilities, training, operations and maintenance, and ordnance costs are considered, the total cost of the program may equal the B-2 program. While a global strike RLV has enormous military potential, affordability is determined by what the nation is willing to spend. The problem is that expensive capabilities sometimes provide low returns on investment that cannot be supported indefinitely. The global strike mission is essentially a "spacelift" mission in which the payload is ordnance. Thus, this study concludes that the global strike mission is not sufficiently compelling to warrant the requisite investment in a major new program at this time. An alternative is that this capability may be more suitable for second or third generation RLVs.

Satellite Servicing Mission. One concept is that a RLV with supporting upper stages, such as the USAF SMV concept, could rendezvous, refuel, upgrade, reposition, or recover space assets.[135] The essential capabilities for a military RLV that is used for satellite servicing include rapid response, small to medium payload capability, high maneuverability so that it can have the extended range that is necessary for servicing distributed satellites, and rated for a human operator.

The ability to orbit and rendezvous with spacecraft that occupy a wide variety of orbits, and to do so without human intervention, requires a degree of technological sophistication that the United States can achieve but has not demonstrated. For example, while supply missions to the Mir Space Station demonstrated the ability to conduct autonomous docking, this operation experienced notable problems, including a collision with a supply spacecraft in 1997.[136] The even greater challenge is the actual servicing of parts that require human presence.

The idea of servicing satellites in orbit is appealing in view of several public successes, of which the most prominent involved the Hubble Telescope and Solar Max. Neither, however, was a military satellite. In fact, the orbits at which a RLV might service satellites do not contain Department of Defense satellites today and are not likely for the foreseeable future.[137] While the problem with satellite servicing is that satellites are not designed for on-orbit servicing, satellite servicing is a worthwhile objective.

For instance, if the United States deploys weapons in space (e.g., space-based lasers or kinetic energy systems for national missile defense), then servicing missions may become necessary for replenishing consumables and keeping weapons operational. However, before this potential mission is pursued by the military, there must be a convincing reason why contractors could not perform the servicing mission. The servicing of space-based weapons is analogous to servicing military aircraft, which is accomplished in many cases by private contractors. But until the U.S. military designs and deploys satellites in orbits that are reachable by RLVs in low-earth orbits, this potential capability has no apparent military utility.

The fundamental alternative to satellite servicing involves the design of the satellite. The U.S. currently designs spacecraft with limited lifetimes that do not generally involve retrieval and refurbishment. As a result, satellites are relatively expensive to build and launch. However, while the ability to lengthen the operational life of satellites is intriguing, the general trend in satellite design is toward less expensive satellites, which reduces the value of refurbishment or repair. The philosophy of throwing away satellites, in contrast with spending money to refurbish them, has the additional benefit of maintaining an inventory of satellites that is ready for launch. If it is desirable to maintain an inventory of satellites, then it is logical to keep those satellites as inexpensive as possible.

A pertinent historical note is that in 1972 Secretary of the Air Force Robert C. Seamans, Jr. argued that satellite servicing was a primary advantage of the Space Shuttle.[138] While this potential has been demonstrated, it has not emerged as a significant role for the Space Shuttle during the last two and a half decades. While satellite servicing holds promise for second-or-third-generation RLVs, satellite servicing does not provide a compelling reason for developing military RLVs.

Global Transport Mission. The concept is use RLVs to transport troops or material rapidly around the globe to prepared sites, which is essentially the mission of the U.S. Transportation Command. While this mission originally interested the U.S. Air Force Space Command, it is currently not part of the Air Force Space Command Phase I Concept of Operations for the Space Operations Vehicle.

The primary challenge to global transport with RLVs is the matter of cost effectiveness. Until the cost of space transport is comparable to rail, sea, or air options, the United States will use these less expensive options. For example, the flight time for a sub-orbital RLV would be less than two hours, and the cost for one pound of payload into orbit would be $1,000. This cost, however, must be compared with conventional military airlift. For example, a C-17 aircraft flying from Charleston, South Carolina to Ramstein Air Base, Germany costs $0.88 per pound and requires a flight time of ten hours.[139] While RLVs can conceivably deliver high priority cargo (up to 20,000 pounds) in eight hours less time, it will be roughly 1,100 times more expensive than conventional airlift.[140] One can imagine scenarios in which eight hours might represent the difference between success and failure, but this is a thin reed upon which to establish the economic rationale for RLVs.

The question then is a matter of optimizing vehicles for cargo missions. The C-5, C-17, and C-130 are all optimized for airlift.[141] As with aircraft, RLVs optimized for delivering cargo will be quite different from those that are designed for global strike, and different still from those that are optimized for placing satellites in orbit. The implication is that the United States would invest in "fleets" of specialized RLVs and SOVs for these missions, but this is unlikely in the current economic climate.

Supportability will also be a major challenge for global transport with RLVs. The destination base must be able park, protect, service, and off-load the RLV. Unless RLVs can use existing runways, taxiways, hangars, and ramps, and take advantage of readily-available fuel and lubricants, then a substantial investment in infrastructure will be required for RLV operations. The ability to conduct worldwide operations implies a degree of supportability that is not currently planned for RLVs. In general, there are materiel and non-materiel alternatives to global transport RLVs that are more cost effective and operationally effective.[142]

While rapid global transport with RLVs is a logical extension of space operations, there is no compelling need to reduce global cargo delivery times by eight hours at a 1,100 fold cost increase. Again, this mission is most likely to emerge for second-or third-generation RLVs, if at all.

Space Control Mission. The objective of space control missions is to use RLVs to temporarily disrupt hostile space assets while protecting U.S. military and commercial space systems.[143] In military terminology, this is known as defensive counterspace operations.[144] The mission of space control is to deny the use of space to an adversary, while protecting U.S. satellites, communication links, and ground stations.[145]

While space control is a vital mission, the role of RLVs in space control is unclear. The U.S. Air Force Space Command argues that RLVs will provide "the means by which USCINCSPACE can maintain freedom of space for friendly forces.[146] RLVs could be used to launch sensors and decoys for protecting friendly forces as well as degrading or disabling hostile space systems with non-lethal means, including jamming.[147] Perhaps the most viable role for RLVs in space control is to identify objects, the ability to conclusively determine if an attack on our assets has occurred, and assess the damage. In essence, the role of RLVs in space control is to provide spacelift, which includes the rapid response, small payload capability, and high maneuverability that are achieved with upper stage vehicles, such as those in the SMV.

The United States needs to protect its space interests, but what is perceived as the weaponization of space may trigger international hostility or an arms race.[148] Another challenge for space control would occur if an adversary intentionally destroyed a satellite and the resulting debris cloud harms other satellites.[149] This is particularly troublesome in the increasingly populated low-earth orbits that contain many constellations of satellites. And a nuclear explosion in space could affect the near-earth space radiation environment for months, and wreak havoc on the electronics in all satellites in particular orbits.

Regardless of whether RLVs are employed, the two primary concerns for performing space control are preventing the escalation of space warfare, and denying adversaries access to commercial satellites that have operational significance (e.g, imagery, communications). [150] While the United States must protect access to space and its vital satellites, it must do so without these

tensions escalating into a war in space. Using RLVs to pursue space control objectives is not by itself escalatory. However, an adversary may perceive U.S. space control with RLVs as so superior that these capabilities become destabilizing.

Nonetheless, the ability to control space is desirable and might be vital for the United States in a future war. The questions then are how to accomplish space control and what is the best role for RLVs. There are several options for space control that may or may not include RLVs. This includes placing attack confirmation and characterization sensors on satellites to provide unambiguous confirmation and characterization of what happened.[151] It also includes research and development in space control but not the fielding of a capability.[152] Other ideas involve striking only terrestrial targets such as ground stations or control nodes, focusing space control efforts on communication links or surgical attacks minimizing or avoiding destruction of on-orbit assets as in jamming signals, and achieving space control objectives through diplomatic efforts. Each of these alternatives can be pursued independently or in parallel, and RLVs could be a part of any of the above alternatives, or none of them.[153]

In the end, political and legal issues will remain the most significant challenge to space control. While this does not negate the need for space control, the United States should carefully consider these issues before it pursues this capability. As to what is the best role for RLVs in space control, the answer is the traditional spaceiift for sensors and emitters. For the purposes of this study, space control may be important, but RLVs have at best a limited role, which is principally to provide spacelift. Thus, space control does not appear sufficiently compelling reason for pursuing RLVs

Spacelift Mission. The objective of spacelift is to provide rapid response to complement dedicated spacelift assets and to do so at low cost. RLVs could perform "launch-to-sustain" or "just-in-time-replenishment" of satellites in the inventory, and perform the rapid reconstitution or expansion of satellites during a crisis.[154] Affordable spacelift has been described as an essential component of space superiority.[155] The essential capabilities and attributes for a RLV for spacelift includes rapid response and small to medium payload capability.

Spacelift requirements generally fit into the two categories of normal and crisis operations in which normal operations include launches to deploy

and sustain operations, while crisis operations encompasses launches to reconstitute capabilities. RLVs could support both normal and crisis launch operations. The reason is that satellite characteristics—size, weight, number being launched at one time, frequency of launches for constellation sustainment, and final destination orbit—are adequately addressed in the design of RLVs. The fact that military space launch will represent less than 10 percent of the worldwide demand for spacelift during the next 20 years means that the launch capacity which is necessary for handling U.S. military needs is unlikely to affect normal launch operations.

There are several problems with reconstitution missions.[156] First, in order to be able to rapidly reconstitute space assets, an inventory of satellites is necessary. Except for the Global Positioning System, the DoD does not normally maintain an inventory of satellites. While there are numerous reasons for this approach, the principal factor is the cost of maintaining an inventory of satellites. And with large constellations, such as the Global Positioning System, the overall capability of the system degrades "gracefully" with individual satellite losses. Second, the DoD does not reconstitute other weapon systems or vital assets this way. For example, if the Air Force exhausts its supply of conventional air-launched cruise missiles in a particular conflict, it might build more missiles or convert nuclear air-launched cruise missiles into conventional ones. Third, the scenarios that deny the use of space assets to the United States, such as a nuclear burst in space or kinetic kill anti-satellite weapons, also deny space to other satellites. Even if additional satellites are available and there is a ready means for delivering them into orbit, it might be prudent to delay the launch in view of radiation or debris. If there is no overwhelming reason for a reconstitution mission, then this diminishes the reason for military spacelift with RLVs.

Another factor that diminishes the case for RLV spacelift is cost. A military program for developing RLVs may not produce lower spacelift costs for the Department of Defense. The research, development, acquisition, and operations and maintenance costs for a RLV will be substantial. To become cost effective, RLVs must cover operating expenses, amortize substantial research and development costs, and fund a new infrastructure.[157] It will take great efficiencies and numerous launches for the DoD to achieve a degree of cost effectiveness that equals the cost of expendable launch vehicles. A fundamental reason is that achieving cost effective RLVs implies that these vehicles are optimized for cost efficiency rather than military requirements.

The U S Department of Defense does not possess tactical satellites that are available for immediate launch in times of crisis. The exception was the launch of two Marine tactical communication satellites during Desert Storm.[158] The Defense Advanced Research Projects Agency has investigated "light-satellites," and the Air Force advocated the development of tactical communication satellites in the mid 1980s. However, the DoD has consciously advocated higher frequency, high power, and survivable satellites for all of the military systems instead of light tactical satellites.[159] The United States could design and build light tactical satellites, but what is missing is an operational requirement. Regional CINCs have openly opposed the development of such assets, preferring to rely on systems that they own and on which they train and deploy.

The U S. Department of Defense can use commercial capabilities for imagery and communications. As with the Civil Reserve Air Fleet for airlift, many military space missions can be covered by leasing commercial assets. In Desert Storm, commercial space assets carried 24 percent of the long-haul communications traffic between the Gulf and the United States as well as numerous intra-theater links.[160] In the case of communications, over 70 percent of daily, routine DoD communications use commercially leased circuits.

While military RLVs could provide spacelift services for the military, the commercial spacelift industry currently provides timely and affordable access to space.[161] With the global demand for spacelift on the rise, the number of firms providing commercial launch services increases each year. The current pace of expendable launch systems is generally sufficient to meet the needs of the U.S. military.

Policy decisions will restrict the military's pursuit of spacelift. In particular, the Commercial Space Act of 1998 prohibits the government from competing with the commercial space industry, and requires the Federal Government to procure commercial space transportation services.[162] In the cases of exceptions, the Secretary of the Air Force must certify that national security considerations preclude using commercially available launch services.[163] The military should anticipate that there will be political pressures to use commercial spacelift to accomplish military requirements. Accordingly, budget constraints, the push for comercialization, and the lack of a consensus on the unique spacelift needs of the military suggest that it will be difficult to convince the Congress to give the military its own spacelift capability.[164]

One factor that limits the ability of the DoD to procure all spacelift from commercial firms is the cost of commercial insurance. In the event of catastrophic launch failures, commercial firms are responsible for the first $500 million of any third party's liability claims, while the U.S. government pays the next $1.5 billion. The 1988 Commercial Space Act created this indemnification arrangement, which was terminated in 1999.[165] When the U.S. policy of indemnifying catastrophic liability comes to an end, launch insurance rates will increase dramatically.[166] If this increased cost is passed on to the customer, the cost of future commercial spacelift might exceed the current costs.[167]

Commercial Utility of Reusable Launch Vehicles

For the commercial space industry, the primary use for RLVs is the traditional mission of deploying satellites into orbits, which is consistent with estimates that within the next 20 years more than 2,700 satellites will be put into space. However there are other potential commercial uses for RLVs, including servicing satellites, high-speed delivery of cargo and global travel, and even the concept of space tourism.

It is estimated that the international space station will require substantial logistical support, perhaps as frequent as one mission every two weeks that carries approximately 50,000 pounds.[168] Studies of the market for the high-speed delivery of cargo suggest that there may be commercial markets for delivery at $500 per pound.[169] According to one study, some private ventures might be able to offer space tourism flights with ticket prices starting at approximately $40,000,[170] while another study estimates that ticket prices of $17,000 could generate demand that exceeds 900,000 passengers annually.[171] Some studies have indicated that there is commercial market for rapid commercial passenger service, as exemplified by a one-hour flight from New York to London.[172] Despite these potential applications for RLVs, the primary market remains that of commercial spacelift.

Commereial Spacelift. The objective of commercial spacelift is to provide routine, reliable, cost-effective, and user-friendly access to space at one tenth of the current cost. The essential capability commercially responsive RLVs in the spacelift application is the ability to respond quickly to requests (within seven days or so) and carry a significant payload.

There are several challenges associated with the development of commercial RLVs. The first is the technical challenge of achieving the operability and reliability that are summarized in Section Two, along with the economic challenges associated with cost and financing. The final category of challenges to the commercial use of RLVs involves the business climate, which refers to the regulatory and policy considerations that affect whether commercial companies attempt to enter the market for a launch services. These include trade policies and agreements, government financial obligations, allocations of risk and indemnification, the cost of and access to government assets and services, Department of transportation licensing, environmental regulations, space traffic control, commercial spaceports, and treaty issues.[173] While a detailed review of these issues is beyond the scope of this study, it is important to establish stable and predictable policies that govern the commercial launch service industry.[174]

The alternative to developing RLVs for commercial spacelift includes the development of evolved expendables and the use of surplus military systems, as exemplified by the Minuteman and Peacekeeper missiles. The space industry estimates that even with the benefits of competition and improved business practices, the use of existing systems might be able to achieve a 25 percent reduction in cost. According to these same estimates, the best cost savings that we can expect from the Evolved Expendable Launch Vehicle might be 50 percent. Furthermore, the other potential commercial applications for RLVs that include satellite servicing,[175] parcel and cargo delivery, global travel, and space tourism are probably appropriate for second-or third-generation RLVs.[176]

Commercial Space Tourism. The broad objective of space tourism is to provide access to space for less than $20,000 per round trip. Some market surveys have indicated that this price will open space tourism to enough of the market to assure success.[177] The essential capability for RLVs that are used for space tourism includes the ability to operate on a scheduled status, a large payload capability with passenger “comforts,” and rated to carry passengers.

The primary challenges for space tourism are to develop a market for reliable, safe, and affordable space flight. Before people will be interested in touring space, safety must exceed that of current levels Launch failures might be tolerated if these resulted in aborted takeoffs that were followed by safe landings. One reasonable target for reliability might be the standard that

applies to commercial airliners, which is clearly higher than that which exists for expendable launches today. With respect to cost, large numbers of flights are essential to amortize the development and production costs rapidly, and as this occurs the dominant factor in cost effectiveness will be the recurring operational costs. If space tourism is to succeed, the reusable system must have an operational efficiency that is 200 times greater than that of the Space Shuttle.[178]

If space tourism is successful, it might encourage or support other space programs, such as the exploration of Mars. It is conceivable that an industry devoted to commercial space might help to amortize the costs that are associated with the development of RLVs, including the costs for vehicles, operating bases, and on-orbit support, and raise the public's support for space travel.[179] Space tourism will only succeed if the cost of space access can be sufficiently reduced. An alternative to space tourism is that of space travel, which includes sub-orbital and even orbital flights.

Summary

The discussion in this section has focused on the military and commercial applications for RLVs. These results are summarized in Table 4, which identifies the optimal characteristics of RLVs for each mission and highlights several key points.

First, as one would expect, the desired characteristics of RLVs depend upon the mission or application. There is no one RLV that fulfills all military and commercial applications. Second, there is a significant degree of overlap in military missions and commercial applications. For example, while the ability to transport personnel has both military and commercial applications, the optimal RLV for transporting military personnel is not the same as the optimal RLV for transporting commercial passengers. Finally, the degree of overlap between military and commercial applications is most pronounced in spacelift and global transport.

Table 4. RLV Military Missions and Commercial Applications

Military Mission	Commercial Application	RLV-Desired Characteristics
Reconnaissance		Rapid Response (RR)/small payload/maneuverable
Global Strike		RR/small to medium payload/ possibly crewed
Satellite Servicing	Satellite Servicing	Mil - RR, medium payload, possibly crewed, maneuverable Civ – Routine, medium payload
Global Transport (cargo)	Global Transport (cargo)	Mil* – RR/large payload/ crewed Civ- scheduled/large payload/ crewed
Global Transport (personnel)	Global Transport (personnel)	Mil* – RR/large payload/ crewed Civ – scheduled/large payload/ crewed
Space Control		RR/small payload/maneuverable
Spacelift	Spacelift	Mil* – RR/small payload Civ – scheduled/med-large payload
	Space Tourism	Scheduled/Large payload/ crewed

* Applies only to the crisis response or reconstitution missions
Legend:

Rapid Response (RR)-ready for mission within two hours
Scheduled-planned missions, response time within seven days
Small payload-less than 10,000 pounds
Medium payload-more than l0, 000 but less than 20,000 pounds
Large payload-greater than 20,000 pounds
Maneuverable-high performance, ability to reach several deployment points per mission, system maneuverability may be achieved through capable upper stages
All reusable launch vehicle versions unmanned unless listed as "crewed" or "possibly crewed"

IV. Conclusions and Recommendations

This section summarizes key findings and conclusions of this study about the military and commercial applications for RLVs. To begin with, it is likely that space will be a growth industry for the next two decades, and that the demand for launches services will increase dramatically.[180] RLVs may be able to reduce the cost of access to space in comparison with the use of expendable boosters and the Space Shuttle. The goal is to develop first-generation RLVs that can reach orbit at a cost of roughly $1,000 per pound.[181] If costs can be sufficiently reduced, a number of military missions and commercial applications probably will emerge so long as it is understood that the fundamental objective is to reduce the cost of access to space.[182]

Technological developments have brought cost-effective RLVs closer to reality. Most technologists are optimistic that we will not face any insurmountable hurdles. That being said, the key areas of technological research are propulsion, lightweight structures, and thermal protection.[183] While U.S. launch vehicles were designed to optimize vehicle flight performance, which led to substantial compromises in operability and reliability, these are the factors that drive the design of commercial RLVs.[184] The result is that military and commercial needs are so fundamentally different that it affects the designs of RLVs for specific applications.[185]

Table 5. Military and Commercial Requirements: Effect on Design

Military Global Strike	Commercial Spacelift	Design Impacts
Rapid Response (mission ready within two hours, 24 hours a day, 7 days a week)	**Scheduled Service** (mission scheduled at least 7 days in advance)	Rapid Response capability is more costly to build and operate than scheduled service. Designs must ensure reusable launch vehicle and support systems (e.g., payload integration, fueling, and maintenance services) can generate missions within two hours.
Potentially Crewed	**Unmanned**	Vehicle reliability and associated human support requirements increase cost, complexity, and reduce available vehicle lift capacity.
Small Payload (20,000 pounds)	**Medium to Large Payload** (50,000 pounds)	Standard payload interfaces improve efficiency of both vehicles, but sunk costs per mission, wear and tear… lead to higher per pound to orbit costs for smaller payloads.

As shown in Table 5, the key characteristics of a military RLV that is used for global strike are substantially different from those of a commercial spacelift RLV. More fundamentally, it is unlikely that RLVs that are designed for military requirements will also be commercially viable. However, RLVs that are designed for commercial applications may have some military value.[186]

While there is substantial interest among governmental agencies and commercial firms in developing RLVs, the best role for the government is to actively participate in technology development efforts rather than to lead design efforts. That is, the government in general and the military in particular should not make the economic decisions that are best left to industry. The implication is that the needs of the Department of Defense should not guide the development of RLV, which was the problem that plagued the design of the Space Shuttle in the early 1970s.

By most standards, the development of RLVs will be expensive, with estimates that development costs will be on the order of billions of dollars. U.S. commercial firms are intent on developing RLVs for spacelift, but this enterprise will need financial assistance if it is to succeed. To finance the development of RLVs, private investors are likely to pursue a number of alternatives.[187] It is likely that RLV development costs will be so expensive that no one private company will pursue this technology by itself, and that these firms will seek to draw some financial assistance from the U.S. government.[188] The general strategy of private firms will be to align governmental and commercial needs in order to pursue several financing alternatives simultaneously, including tax credits, loan guarantees, advance purchase agreements, cooperative research and development, matching funds, direct equity investments, federal financing, and bonds. Perhaps the optimal strategy is to develop commercial RLVs in the hope that military missions and other profitable applications, including cargo, passenger service, and tourism, may follow.

While there are numerous potential military missions that can be performed by RLVs, neither the economic climate nor the budget will support a vigorous Department of Defense program to develop RLVs for traditional air missions in space Table 6 reviews the military missions advocated for reusable launch vehicles and summarizes some challenges and alternatives.

Table 6. Missions and Applications

Mission	Challenges and Alternatives
Reconnaissance	*Challenges*: Pressing need may not exist, timeliness; weather; telemetry, tracking, and commanding; interoperability - may not fit within Joint architectures *Alternatives*: Expanded use of commercial satellites, continue to improve national capabilities, unmanned aerial vehicles
Global Strike	*Challenges*: National policy, adversary and allied reaction; mission drives unique design requirements which drive costs *Alternatives*: Cruise missiles and other stand-off weapons, continued investment in stealth
Satellite Servicing	*Challenges*: Cost effectiveness given orbit dynamics, no current military missions identified *Alternatives*: Satellite design, wait for 2nd or 3rd generation reusable launch vehicles
Global Transport	*Challenges*: Cost effectiveness/worldwide supportability, requires prepared base at originating and end point - not suitable for rapid troop insertion/covert operations. *Alternatives*: Traditional lift (land, sea, and air), wait for 2nd or 3rd generation reusable launch vehicles. From a cargo perspective, pre-positioning seems better or wait 10 hours for conventional airlift. Hard to find cargo mission of sufficient import to justify this mission
Space Control	*Challenges*: Specific role for reusable launch vehicle unclear – perhaps as a surveillance platform; national will, senior level decision-making, legal implications associated with targeting commercial satellites, unintended consequences *Alternatives*: Diplomatic efforts, ground-based actions, reduce vulnerabilities, passive actions, preparedness
Spacelift	*Challenges*: Reconstitution or crisis mission timelines, inventory cost *Alternatives*: Commercialize all spacelift, continue use of expendables, and use surplus military assets.

The reality is that none of these missions warrant a vigorous program for developing RLVs. By far the most compelling reason for RLVs is spacelift, but in this case the DoD should not compete with commercial industry, for three reasons. The first is the restrictions articulated in the U.S. national space policy. Second, there is not sufficient demand to justify a separate military lift capability. Third, with the exception of weapons deployment, there is no compelling DoD unique requirement that cannot be accomplished with commercial means.[189]

Accordingly, a major finding of this study is that RLVs and their associated support facilities should be designed from the start to be cost-effective, which means that the focus must be on operability and reliability rather than strict military requirements.

Historically, the struggle between military requirements and cost efficiency has, as in the case of the Space Shuttle, led to "cost increases, new launch-site requirements, and ultimately schedule delays."[190] The current fleet of U.S. expendable boosters (Atlas, Delta, and Titan) evolved from 1950s/1960s intercontinental ballistic missiles, which focused on non-commercial attributes.[191] Table 7 outlines the distinctions between RLVs that are optimized for military missions and those that are designed for commercial purposes.

Table 7. Design Attributes Militarily Responsive versus Cost-Optimized

Attribute	Militarily-Responsive	Cost-Optimized
Payload	10,000 to 20,000 pounds	20,000 to 50,000 pounds
Alert	Rapid response within hours	7 days to ready for mission
Man-Rated	Deemed essential for certain missions by some, desirable for other missions	Unpiloted, but rated to transport humans as "cargo"[192]
Support Facilities	Military controlled, secure, optimized for rapid fueling, maintenance, launch	Open to public/customers (especially foreign), located for convenience, tax breaks, optimized for cost effective ops
Performance	Highly maneuverable system, large cross track capability desired	Get up and down with minimum cost

The Department of Defense has demonstrated the ability to develop outstanding operational and technical capabilities, but the same is not true for cost efficiency. Until now, military systems focused on performance. The fact that reducing the cost of access to space is an important national interests, it follows that the military should not lead or unduly influence the design and operation of RLVs. This does not mean, however, as some have argued, that the, military should stay out of RLV design, and that the United States should accept whatever is developed by the commercially world.[193] The real issue is the difference between RLVs designed for militarily purposes and RLVs designed for commercially applications. While both share common performance objectives—placing payloads into orbit—the military focuses on performance, while the commercial world focuses on cost efficiency. This study concludes that the best course of action for the U.S. is to pursue commercial spacelift vehicles first.

The Department of Defense should support the development of commercial RLVs. After observing commercial operations with the first generation of commercial RLVs, the military could use this experience to refine military doctrine, strategy, and tactics for the future employment of RLVs. At some point, it might be prudent to lease a commercial RLV and work with contractors in order to gain first-hand operational experience. In that case, the military could procure second-or third-generation RLVs for specific military missions that commercial firms cannot provide. The military does not need to own and operate unique military RLVs because commercial vehicles will satisfy most military requirements. With the possible exception of employing weapons, commercial firms could place any payload into orbit for the military. A fundamental conclusion of this study is that the most effective and efficient strategy is to allow economic forces shape the design, development, manufacture, and operation of RLVs, and that eventually the military should adapt the first-generation commercial RLV to support military missions.[194]

RLVs that are optimized for commercial operations can provide the lift for many specialty military payloads, while the military should focus on developing highly maneuverable upper stages—such as U.S. Air Forces SMV concept to take advantage of rapid, low-cost commercial lift. As examined in this study, the only two unique military missions for RLVs—global strike and space control—involve using weapons and hence are unsuitable for the commercial world.

As long as it is not politically or militarily necessary for the United States to conduct these missions, the U.S. military should make the transition out of the spacelift business. Second, the U.S. military should not plan to use RLVs for traditional air power missions in space for the foreseeable future.

Recommendations

The U.S. military should allow commercial firms to dominate the spacelift business. While RLVs are in their infancy, it will be necessary to optimize designs for maximum cost and operational efficiency, which should lead to profitable operations and a market share. Commercial companies essentially perform all military launch operations today with oversight from the military. The next generation of expendable spacelift, the Evolved Expendable Launch Vehicle, will perform all military scheduled spacelift on a fee for service basis.[195]

During "launch operations" today, DoD personnel manage the launch contract, certify to the chain of command that all is ready for launch, ensure protection of unique government resources (typically launch support facilities), and verify compliance with safety programs, policies, and procedures. DoD personnel never touch a wrench, turn a valve, operate a crane, or "push the button" that launches a rocket. Space launch operations are different from ballistic missile operations.[196] In the case of spacelift, however, the government is losing the ability to maintain a military capability (spacelift) when the commercial world is thriving. As commercial RLV operations mature, the Department of Defense should consider leasing several commercial RLVs for operational test and evaluation. It is quite possible that RLVs will need to be built and operated by the commercial sector before their utility is appreciated or the best methods of military employment are discovered.[197] To keep military personnel familiar with spacelift operations, military personnel could work in commercial contractor launch operations and learn how to operate and maintain RLVs. These individuals would then constitute the core RLV program in the military when the military operates such vehicles.

As the military moves away from controlling traditional spacelift, it should focus on the strategy, doctrine, and tactics that are associated with global strike and space control. The opportunity to observe commercial RLV operations will provide substantial insights for the military personnel who will employ RLVs in the future.

U.S. military should not use RLVs for traditional air power missions in space. The missions of reconnaissance, global strike, global transport, and space control offer great potential and are perhaps the logical extension of air and space power, but these are of limited value at present. To pursue these capabilities might provoke a race to weaponize space and ultimately create political instability.

There is presently no national security shortfall, unfulfilled requirement, or demonstrated military utility that is sufficiently compelling to justify a program to develop military RLVs.[198] The proposed military missions are variation of spacelift, and in a similar fashion there is no sufficiently compelling commercial reason for developing RLVs without government investment given the magnitude of the resources required. The primary reason for the United States to develop RLVs is for the purpose of spacelift.

The first priority is to reduce the cost of access to space, which is the key to what the United States, wants to accomplish in space. The way to reduce the cost of access to space is to develop RLVs whose designs are optimized for operability and reliability. In exchange for business guarantees and financing assistance, the government could achieve "most favored customer" status with commercial launch service firms. The current partnering arrangements between industry and NASA on the X-33, X-34, and Future-X vehicles are exemplars of the formalized agreements between NASA and the DoD that will take the United States in the right direction.

In conclusion, the fundamental reason for the United States to develop RLVs is to reduce the cost of access to space. Therefore, RLV designs should emphasize cost efficiency, which means that commercial firms with financial assistance from the government should drive the development of RLVs. The essence of military RLVs is spacelift, and with the possible exception of employing lethal force, commercial RLVs will accomplish the needs of the military. In view of the superiority and flexibility of U.S. military capabilities, there is no compelling reason for the military to develop RLVs for military applications. With the right investment strategy, the United States can develop RLVs and use that technology to support the nation's objectives of maintaining leadership in space, while ensuring U.S. military security and economic prosperity.

Glossary

Active Defense-detect, track, identify, intercept, and destroy or neutralize enemy space and missile forces.[199]
Assured Access to Space-the ability to get to space

CINC-Commander in Chief

CM-Cruise Missile
CONUS-Continental United States
Counterspace-the mission carried out to achieve space control objectives by gaining and maintaining control of activities conducted in or through the space environment. Offensive counterspace operations use lethal or non-lethal means to achieve five major purposes: deception, disruption, denial, degradation, and destruction of space assets or capabilities. Defensive counterspace operations consist of active and passive actions to protect US space-related capabilities from enemy attack or interference. [200]
CRAF-Civil Reserve Air Fleet

Deception-measures designed to mislead the adversary by manipulation, distortion, or falsification of evidence to induce the adversary to react in a manner prejudicial to their interests. [201]
Denial-the temporary elimination of the utility of the space systems, usually without physical damage. [202]
Degradation-the permanent impairment of the utility of space systems, usually with physical damage. [203]
Destruction-the permanent elimination of the utility of space systems, usually with physical damage.[204]
Disruption-the temporary impairment of the utility of space systems usually without physical damage to the space segments.[205]
DoD-Department of Defense

Geosynchronous Orbit-orbits 22,279 statute miles in altitude above the Earth Geostationary orbits are special form of Geosynchronous orbits with 0 degrees inclination and match the Earth's rotation.[206]

ICBM-Inter-Continental Ballistic Missile
ISR-Intelligence, Surveillance, and Reconnaissance

Launch to augment-a strategy to increase operational capability above the designed operational capability in response to war, crisis, or contingency. [207]
Launch to deploy-a strategy using a launch or series of launches required to initially achieve a satellite system's designed operational capability. [208]
Launch to sustain-a strategy to replace satellites predicted to fail or that fail abruptly. [209]
Low Earth Orbit-orbits ranging from 100-250 nautical miles in altitude above the Earth.[210]

NASA-National Aeronautics and Space Administration
NCA-National Command Authorities

Passive Defense-reduce the vulnerabilities and protect and increase the survivability of friendly space forces and the information they provide.[211]

RLV-Reusable launch vehicle.

Space Sanctuary-a condition of equilibrium where no new space weapons are introduced, that is "cap the current level of space weaponization *where it stands today.*"[212]
Spacelift-the ability to project power by delivering satellites, payloads, and material into or through space.[213]
SMV-Space Maneuver Vehicle
SOV-Space Operations Vehicle.
SLBM-Submarine Launched Ballistic Missile.
Space Control-operations to assure the friendly use of the space environment while denying its use to the enemy. Achieved through offensive and defensive counterspace carried out to gain and maintain control of activities conducted in or through the space environment.[214]
Space Systems-consist of three elements: space, terrestrial, and link.[215]

UAV-Unmanned Aerial Vehicle.
U.S.-United States.
USAF-United States Air Force.

Notes

1. The Air Force mission statement is "To defend the United States through control and exploitation of air and space." The Air Force vision statement is "Air Force people building the worlds most respected air and space force-global power and reach for America." See http://www.af.mil/news/factsheets/organization_of_the_United_St.html. December 28, 1998.

2. Director of Plans. "Future Strategic Environment," US *Space Command Long Range Plan* (Peterson Air Force Base, CO: March 1998), p. 3.

3. *Ibid.*

4. Ibid.

5. A National Security Strategy For a New Century, p. 25.

6. Andrew J Butrica, "Commercial Spaceports: Hitching Your Wagon to a Venture Star," *Space Times,* (October 1998), pp. 6-7.

7. John A. Tirpak, "The Flight to Orbit," *Air Force Magazine,* (Arlington, VA: Air Force Association, November 1988), p. 41.

8. Commercial space activity is predominantly associated with communication services but remote sensing is becoming more important. Both areas are projected to experience continued growth but other potential commercial uses of space (e. g., manufacturing, tourism) are unlikely to emerge given the high cost of getting to space. See John J. Egan, "Perspective on Space Commerce - Is it Real?" *Space Energy and Transportation* Vol. 2, No. 1, 1977, (Arlington, VA: High Frontier Publications), pp. 12-19.

9. Carl Builder distinguishes between strategic and tactical terms through several contrasts: strategic thinking focuses on ends in which the objective is to go to the heart of the matter, while tactical thinking focuses on means and with the objective of dealing with the matter at hand. Builder differentiates between the two terms by identifying strategic thinking as addressing the question "What are our national interests and objectives?," while tactical thinking addresses the question "What is the military objective?" For this argument, see Carl H. Builder, "Keeping the Strategic Flame," *Joint Forces Quarterly Summer,* 1998, Number 19 (Washington, D C.: Institute for National Strategic Studies, National Defense University Press, Summer 1998), pp. 77-78.

10. The first generation of RLVs refers to emerging concepts that are likely to result in production vehicles. Subsequent generation vehicles will exhibit higher performance (e.g., altitude and payload), more durable airframes, more durable propulsion, and generally faster turn-around times between missions. For example, a first generation vehicle might have a flight propulsion system that lasts for 25 flights, while a second generation vehicle might push that to 50 flights, and a third generation vehicle might have a 500 night propulsion system. This characterization is derived from research in progress at the HQ AFSPC DRS.

11. The six themes are 1) space has been important in the past to military operations, and will be more important in the future, 2) the United States and other space powers are on the verge of a dramatic growth in commercial space; 3) space is emerging as a vital national interest because of its military and economic importance, 4) since space is a growing source of national power, it will be challenged, 5) the U.S. military must be ready when challenged in space to use its armed forces, and 6) the responsibility falls to the US Space Command to ensure access to and protection of US interests and investments in space. See Director of Plans "Introduction," US *Space Command Long Range Plan* (Peterson Air Force Base, CO: March 1998).

12. Director of Plans. "Future Strategic Environment," US *Space Command Long Range Plan,* p. 3.

13. As a former Commander in Chief of the USSPACECOM acknowledged, "The shift will continue from the military to the commercial sector as the dominant receiver and provider of space services." *Ibid.*

14. This forecast does not include scientific, technology development, or remote sensing spacecraft.

15. This number excludes classified programs. Terri Lehto. "Space Systems *Analysis 3* - Commercial Communication Satellites 1998-2017," *DMS Markel Intelligence Reports* (Alexandria VA: Janes Information Group, July 1998), pp. 23, 28**;** "Space Systems Analysis 4 -- Western Military Satellites - 1998-2007," (Alexandria, VA: Janes Information Group, July 1998), p. 13.

16. Two related points are that the projection of 2700 satellites does not equate to 2700 launches because it will be common to launch multiple satellite. This forecast also *excludes* "eastern military satellites" and western classified satellites for which there are no reliable estimates. See Terri Lehto. "Space Systems Analysis 2 - The World Market for Expendable Launch Vehicles -1998-2017," *DMS Market Intelligence Reports* (Alexandria, VA: Janes Information Group, July 1998), p. 4.

17. In 1998 there were 73 space launches worldwide (36 from the U.S.) that attempted to place 149 satellites in orbit, re-supply the Mir space station, or begin construction of the International Space Station. Four of the 73 launches, which carried 15 satellites, failed to achieve orbit. The 149 satellites planned for launch in 1998 break down as follows: 115 commercial, 17 civil, and 17 military. See http://vww.flatoday.com.space/next/98log.htm, December 28, 1998.

18. This includes 28 distinct types from at least 9 countries. The U. S. share of this launch market is estimated at 48 percent. See Terri Lehto, "Space Systems Analysis 2," p. 2-7.

19. William B. Scott, "McPeak, Hecker Head 'Space-Plane' Project," *Aviation Week & Space Technology* (March 10, 1997), p 23.

20. Jay P. Penn and Dr. Charles A Lindley, "RLV Design optimization for Carrying People To and From Space," *Space & Energy Transportation,* Vol. 2, No. 3, (1997), p. 153.

21. This would theoretically yield a profit that is five times greater than current values. See William B Scott, "Air breathing HyperSoar Would 'Bounce' on Upper Atmosphere," *Aviation Week & Space Technology* (September 7, 1998), p. 126.

22 Egan, p. 17.

23. The global transport mission was originally of high interest to the military for moving equipment and Special Operations Forces. First drafts of the SOV CONOPS contained this mission as a priority, but the final Phase I SOV CONOPS no longer actively pursues this mission. See HQ AFSPC DOMN, *Concepts of Operations for the Phase I Space Operations Vehicle System,* (Peterson Air Force Base, CO, February 6**,** 1998), pp. 5-6.

24. David N. Spires, *Beyond Horizons: A Half Century of Air Force Space Leadership* (Peterson Air Force Base, CO: Air Force Space Command, 1997), p. 4.

25. *Ibid.,* p. 175.

26. Roger D. Launius, "Toward an Understanding of the Space Shuttle: A Historiographical Essay," *Air Power History* (Lexington, VA: Air Force Historical Foundation, Winter 1992), p. 8.

27. Spires, pp. 181-182.

28. HQ AFSPC action officers calculate that this decision no longer made financial sense at Space Shuttle mission number 76 (calculations exclude inflation). See Spires, p. 182.

29. Ray Peterson. - "Space Systems Forecast," *DMS Market Intelligence Reports* (Alexandria, VA: Janes Information Group, February 1998), p. 1.

30. At least one study suggests that NASA will phase out Space Shuttle fights to the International Space Station by 2004-2005. The Venture Star would accomplish International Space Station re-supply with ten flights per year and save over $1.5 billion annually See Joseph C. Anselmo, "Kill the Shuttle? RLV Debate Heats Up," *Aviation Week & Space Technology* (November 30, 1998), p. 67.

31. John R. London 111, *LEO on {he Cheap: Methods far Achieving Drastic Reductions in Space Launch Costs,* Research Report No. AU-ARI-93-8 (Maxwell Air Force Base, AL: Air University Press, 1994), p. 98.

32. The investment in 1998 was $86 million, with an additional $29 million for technology development See "Military Spaceplane Briefing" (Wright-Patterson Air Force Base, OH: Air Force Research Laboratory, February 1998).

33. See http://www.hq.nasa.gov/office/pao/History/X-33/dc-xa htm.

34 See http://www.hq.nasa.gov/office/pao/History/X-33facts_1.htm.

35. The key areas that were demonstrated and evaluated included flight controls, reaction control systems, vertical takeoff and landing systems, an in-flight abort, in-flight vertical rotation maneuver, and auto-land capability. See http://www.hq.nasa.gov/office/pao/History/X-33/dc-xa.htm, October 8, 1998.

36 Thc DC-X was 40 feet high, 13.5 feet across at the base, and conical in shape. When empty the DC-X weighed 20,000 pounds and could carry 21,600 pounds of liquid oxygen and liquid hydrogen. The DC-X was powered by four RL-10A5 rocket engines each of which is capable of generating 13,500 pounds of thrust. The primary structural members of the DC-X were aluminum, titanium, and steel. The DC-X used off the shelf avionics, including F-15 navigation system, F-18 accelerometer and rate gyro package, and GPS P(Y) code receiver. See "DC-X Fact Sheet," October 8, 1998, p. 2. See also http://www hq.nasa.gov/offce/pao/History/x-33/dcx-facts.htm.

37. In reality, the turnaround time was 26 hours. The range closed due to hazardous local weather conditions.

38. "The Delta Clipper Experimental: Flight Testing Archive," October 8, 1998, pp. 2-3, http://www.hq.nasa.gov/office/pao/History/x-33/dc-xa.htm.

39. This funding data provided by Lt Col Jay McDaniel, Air Force Research Laboratory liaison to NASA, January 15, 1999.

40. Lehto, "Space Systems Analysis 2," p. 5.

41. See http://wwwl.msfc.nasa.gov/NEWMSFC/xplanes.html p. l.

42. See "X33, What is X33?" October 8, 1998, http://stp.msfc.nasa.gov/stpweb/ x33/x33about. html.

43. The X-34 vehicle is 58.3 feet long, 27.7 feet wide at the wing tips, and 11.5 feet tall. NASA awarded a contract to Orbital Sciences Corporation for $50 million to build and test-fly the X-34. The government has increased funding for long lead items and has an option to build a second X-34. See Lehto, "Space Systems Analysis 2," p. 5.

44. "X34 Objectives," October 8, 1998, pp. 1-2. See also http://stp.msfc.nasa.gov/ stpweb/x34/x34objectives.html.

45. Tirpak, "The Flight to Orbit," p. 43

46. These missions are examined in more detail in Section Three.

47. HQ AFSPC/DOMN, *Concepts of Operations for the Phase I Space Operations Vehicle System,* pp. 5-6.

48 *Ibid., p.* 6.

49. HQ AFSPC action officers report that the X40A completed its first drop test in August 1998 and successfully completed an autonomous landing. NASA's Advanced Technology Vehicle program plans a drop from the Space Shuttle in the near future. See Tirpak, "The Flight to Orbit," p. 43.

50. As of December 18, 1998, the following companies listed in Table 1 were registered as official X-Prize competitors: Scaled Composites - Burt Rutan, Pioneer, Advent, Kelley, and Lone Star Space Access. See http://www.xprize.org/teams/ index.html.asp?client=4441.

51. Peter H. Diamandis, "X Prize Foundation," September 27, 1998, http://www.xprizeorg/info/index/html.asp.

52. See http://www seds.org/spaceviews 971115/pol.html, December 18, 1998.

53. "Reusable Launch Vehicle Countdown." December 27, 1998, http://misa02.msi.se/~lindsey RLVCountdown html.

54. Delta launch price supplied by HQ AFSPC/DO action officer during author interview, February 26, 1999.

55. Ray Peterson, "Space Systems Update" *DMS Market Intelligence Reports* (Alexandria, VA: Janes Information Group, January 1998), p. 2.

56. Payment is contingent upon successful launches. See http://msia02.msi.se/~lindsey/RLVCountdown.html, December 18, 1998, p. 2.

57. Peterson, "Space Systems Forecast," p 1.

58. William B. Scott, "McPeak, Hecker Head 'Space-Plane' Project," *Aviation Week & Space Technology* (March 10, 1997), pp. 22-23.

59. Peterson, "Space System Forecast," p. 2.

60 Penn and Lindley, p. 154.

61. "Britain's Space Plane" *Futurist,* Vol 28, No 4, (July/August 1994), p. 6.

62. See http://www.bristolspaceplanes.com projects/ascender.shtml, November 21, 1998, pp. 1-5.

63. See http://www.nal.go.jp/www-e/juuten/hope/home.html, November 21, 1998, p. 1.

64. Scott, "Airbreathing HyperSoar Would 'Bounce' on Upper Atmosphere," pp. 126-130.

65. This review of technical challenges benefited from discussions with commercial industry sources. See also "Spacelift: Suborbital, Earth to Orbit and On - orbit," *Spacecast 2020 (*Maxwell Air Force Base, AL: Air University Press, 1994), p. H-25.

66. Major Michael J. Muolo et. al., *Space Handbook: An Analysts Guide,* Volume 11 (Maxwell Air Force Base, AL: Air University Press, December 1993), p. 55.

67. *Ibid,* p. 214.

68. Ovid W. Eshbach and Mott Souders, *Handbook of Engineering Fundamentals,* 3rd edition (New York, NY: John Wiley & Sons, 1975), p. 1328.

69. Information provided by HQ AFSPC/DRS action officer during interview, February 26, 1999.

70. Information obtained from industry sources during author interview on December 4, 1998.

71. "The Delta Clipper Experimental: Flight Testing Archive," October 8, 1998, pp. 2-3. See http://www.hq.nasa.gov/office/pao/History/x-33/dc-xa.htm.

72. HQ AFSPC/DOMN, *Concepts of Operations for the Phase I Space Operations Vehicle System,* p. 3.

73. See http://astp.mstc.nasa.bov/stpweb/showme.html.

74. The specific wording includes "Future - X vehicles and flight experiments will demonstrate technologies that improve performance and reduce development, production and operating costs of future Earth-to-orbit and in-space transportation systems. The cutting-edge technologies to be demonstrated through Future-X are aimed at increasing U.S. competitiveness in the worldwide commercial space transportation market and decreasing future government costs for space access." See http://spaceling.mstc.nasa.gov/NASA.News/NASA…/98-12-08 Future - X.Cooperative.Agreement, January 1, 1999, p. 1.

75. See http://www.boeing.com/defense/space/space/futurex.futurexfeatures.html.

76. Information provided by Lt Col Jay McDaniel, Air Force Research Laboratory liaison to NASA, January 15, 1999.

77. See http://astp.msfc.nasa.gov/stpweb/astp/art/ARThome.html.

78 See http://spaceling.mstc.nasa.gov/NASA.News/NASA…98-12-08 Future-X.Cooperative.Agreement, January 1, 1999, p. 2.

79. View expressed by members of HQ AFSPC/DRS division Email with author, January, 31, 1999.

80. See http://x33.msfc.nasa.gov/x33about.html.

81. Views expressed by members of HQ AFSPC/DRS division. Email with author, January 29, 1999.

82. The manufacturing cost for each reusable launch vehicle is estimated to be in the range of $750 million to $l billion. See Jamie G. G. Varni, “Space Operations: Through the Looking Glass,” *2025 Study* (Maxwell Air Force Base, AL: Air University Press, 1996), pp. 227, 233.

83. Lockheed Martin’s VentureStar, perhaps the best poised reusable launch vehicle endeavor, requires loan guarantees before it can proceed with commercial development, according to Rep. Dave Weldon (R-FL). See “Spaceviews,” Issue 1999.02 02, February 22, 1999, p. 4. See http://www spaccviews.com/999/0222. See also Joseph C. Anselmo, “Kill the Shuttle? RLV Debate Heats Up,” *Aviation Week & Space Technology* (November 30, 1998), p. 68.

84. Some take issue with this view calling it shortsighted, which may be true. But just because spacelift has been done one way does not mean there are not better approaches in the future.

85. President Clinton’s National Space Policy, September 16, 1996: “The United States is committed to the exploration and use of outer space by all nations for peaceful purposes and for the benefit of all humanity ‘Peaceful purposes’ allow defense and intelligence-related activities in pursuit of national security and other goals. The United States rejects any claims to sovereignty by any nation over outer space or celestial bodies, or any portion thereof, and rejects any limitation on the fundamental right of sovereign nations to acquire data from space. The United States considers the space systems of any nation to be national property with the right of passage through and operations in space without interference. Purposeful interference with space systems shall be viewed as an infringement on sovereign rights.”

86. Specifically, it requires states to supervise and regulate private space activities.

87 The specific wording is that, “The objective of NASA’s technology demonstration effort is to support government and private sector decisions by the end of this decade on development of an operational next-generation reusable launch system. The objective of DoD’s effort to improve and evolve current ELVs is to reduce costs while improving reliability, operability, responsiveness, and safety. The United States government is committed to encouraging a viable commercial U.S. space transportation industry.” Michael A. Rampino, *Concepts of Operations for a Reusable Launch Vehicle* (Maxwell Air Force Base, AL: Air University Press, 1997), p. 1.

88. The Air Force is particularly interested in a RLV program that can be tuned around within hours, reduces launch costs by a factor of 10 to 100, reduces operations and maintenance costs substantially, deploys a Space Maneuver Vehicle with a payload to low earth orbit, and develops and uses a Modular Insertion Stage to deploy satellites into low-earth orbit. See HQ AFSPC/DOMN, *Concepts of Operations for the Phase I Space Operations Vehicle System,* p. 4.

89. The Department of Transportation has the formal authorization to proceed with a commercial launch Licensing acknowledges that the commercial firm complies with the regulatory provisions that the United States has deemed are essential to comply with the national and intentional obligations and responsibilities that are associated with launching objects into space. See Legislative recap on HR1702, Commercial Space Act 1998, flp://flp.Ioc.gov/pub/thomas/c105/h1702.ih.txt.

90. *Air Force Basic Doctrine,* Air Force Doctrine Document 1, (September 1997), pp. 84-85.

91. NAIC/PO, *Threats to US Military Access to Space* (Wright-Patterson Air Force Base, OH: NAIC Press, Fall 1998), p. 2.

92 Bill Gertz, "Chinese Army is Building Anti-Satellite Laser Weapons," *The Washington Times,* November 3, 1998), p. 1.

93. General Thomas Moorman, former Air Force Vice Chief of Staff and former Commander, Air Force Space Command, recently expressed the view that, "Right now they are not real interested in being protected. A common response from industry [about satellite protection] is that's what insurance is for." General Thomas Moorman (ret), *Defense Daily,* (Arlington, VA: Phillips Business Information, Inc., January 19, 1999), p.2.

94. See http://edcwww.cr.usgs.gov/glis/hyper/guide/disp, February 2, 1999, p. 4.

95. Three-foot imagery can be used to locate street centerlines, buildings, bridges, railroads, canals, and elevation contours to within a 20 feet of horizontal and vertical accuracy. See http://www.digitalglobe.com/applications/07.html, February 2, 1999, p. 1. One internet advertisement reads in part, "Aching for a look at Pakistan's nuclear test facilities? Curious where Saddam's chemical weapons labs might be located? You don't need to bother with top-secret clearance. Just slip out your credit card." Space imaging will use the IKONOS satellite and anticipates selling several square miles of images for a few thousand dollars. In a voluntary arrangement with the U.S. government prior to licensing, the firm Space Imaging agreed not sell images of U.S. military installations, Israel, or other "sensitive areas." See http://www.discovery.com/stories/unofficialspace/980623/space.htm, October 30, 1998, pp. 1-3.

96. The HQ AFSPC/DO plan is to use the SOV for counterspace operations, real-time protection of domestic and friendly force on-orbit assets; rapid recoverable intelligence, surveillance and reconnaissance; satellite deployment, redeployment, recovery, upgrade, refueling and repair; space-based deterrence in areas unreachable by land, sea, and air forces; space-based resource integration into the conventional force package; and worldwide weapons delivery within minutes of launch. See HQ AFSPC/DOMN, *Concepts of Operations for the Phase I Space Operations Vehicle System,* pp. v-vi.

97. *Ibid.,* p. 5.

98. *Ibid.,* p. 19.

99. Time delays are often attributed to physical positioning of reconnaissance assets, the administrative process for requesting support, and the relative priorities assigned to users.

100. HQ AFSPC/DOMN, *Concepts of Operations for the Phase I Space Operations Vehicle System,* p. 7.

101. Rapid response refers to something less than the traditional alert status in which forces are able to generate a mission 24 hours per day, 7 days per week. For RLVs, satisfactory performance is probably being able to generate a mission within hours instead of days. This means the capacity to carry three or more deployable satellites with maneuver capability that is sufficient to achieve the desired orbital parameters and maintain that position and attitude over time.

102. See *Joint Vision 2010* (Washington, DC: Department of Defense, 1996).

103. Craig Covault, "New intelligence Ops Debut in Iraqi Strikes," *Aviation Week & Space Technology* (December 21/28, 1998), pp 124-125.

104. The purpose is to not only "beat" the national asset on its next pass, but to fill coverage gaps and reduce the revisit time.

105. While overall timelines can be improved with procedural and hardware changes, some actions, such as thermal and vibration stabilization, require time. This judgment is based on the author's personal experience as the Atlas Launch Squadron Commander (June 1996-June 1998) in processing and launching the Defense Satellite Communications System satellite. The spacecraft arrived at Cape Canaveral Air Station on June 17, 1997 and were launched on October 24, 1997. The satellite was declared operational on-orbit in late February 1998.

106. This particular concept did not estimate the system acquisition or total life cycle costs, but was intended to show a credible estimate of the cost of operations. This estimate included one flight for each vehicle each week. The Black Horse concept is described in Spacecast 2020 as an "F-16 fighter size" spacecraft with operating costs that are derived from the actual operating cost data for the SR-71 aircraft, whose cost per flight hour was estimated to be in the $100,000 range. See "Spacelift: Suborbital, Earth to Orbit and On-Orbit. Black Horse Operating Cost Estimates," *Spacecast 2020,* Appendix H, pp. H-55-56.

107. HQ USAF/XOIR, "Commercial Satellite Imagery Integration Plan," (July 15, 1998), pp. 1-5.

108. Major Ken Verderame, DRAFT *Military Spaceplane Handbook for Wargamers (*Kirtland AFB, NM: Military SpacepPlane Program Office, August 25, 1998),p. 11.

109. David A Longino, *Role of Unmanned Aerial Vehicles in Future Armed Conflict Scenario (*Maxwell Air Force Base, AL: Air University Press, December 1994), p. 24.

110. UAVs provided invaluable support to the Army, Navy, Air Force and Marines during the Persian Gulf War. UAVs are credited with enabling the services to destroy every piece of enemy artillery that posed a threat to advancing friendly forces. UAVs also were used to spot all naval sixteen-inch gunfire. And the Marines deployed with the Pioneer as an organic asset and deemed it to be indispensable in providing information direct to the Marines. Longino, pp. 9-10.

111. The SOV need not achieve orbit to apply force because a sub-orbital flight profile could deploy weapons on a trajectory similar to that of a ballistic missile. HQ AFSPC/DOMN, *Concepts of Operations for the Phase I Space Operations Vehicle System,* p. 11.

112. These key attributes were provided to the author by HQ AFSPC/DRS action of

officer through e-mail, February 5, 1999.

113. For reusable launch vehicles, a satisfactory "alert" performance is probably the ability to generate a mission within hours instead of days. While a number of concepts for RLVs could be unmanned, there are currently opposing views within the Air Force that remain unresolved. The current HQ AFSPC/DOMN, *Concepts of Operations for the Phase I Space Operations Vehicle System,* provides for some manned missions, but current studies tend to favor unmanned options. However, some powerful advocates within the Air Force hold that manned, positive control over weapons release is preferable and required. Many concepts could be unmanned, but there are opposing views within the Air Force about this issue.

114. Verderame, pp. 15-17.

115. The assumption is that any such system would have to pass internal DoD reviews for affordability before moving from the drawing board to the flight line.

116. See http://www.af.mil/news/factsheets/AGM_86B_C_Missiles.html, December 28, 1998, p. 3.

117. See http://www.chinfo.navy.mil/navpalib/factftle/missiles/wep-toma.html, December 28, 1998, p. 1.

118. This capability could complement the Air Expeditionary Force by enabling rapid strikes in regions without deployed forces.

119. See http://www.af.mil/news/factsheets/AGM 86B_C_Missiles.html, December 28, 1998, p. 2.

120. Robet Wall, "New Weapons Debut In Attacks on Iraq," *Aviation Week & Space 2echnology* (December 21/28, 1998), p. 14.

121. It is estimated that a 2,250 pound Common Aero Vehicle (CAV) could carry 1,200 pounds of precision guided munitions, which equates with one conventional precision guided munition for each Common Aero Vehicle. Using these weight estimates, the SOV could carry a maximum of 10 CAVs or 10 weapons.

122. This availability tracks with the HQ AFSPC wartime surge objective of 1 sortie per day for 4 days. HQ AFSPC/DOMN, *Concepts of Operations for the Phase I Space Operations Vehicle System,* p. 31.

123. Freedman describes how the West was driven to seek continual advantage over the Soviets once they had obtained nuclear weapons. Lawrence Freedman, *The Evolution of Nuclear Strategy* (New York*:* St Martins Press, 1981), p. 131.

124. This view was expressed by an HQ AFSPC/DRS action officer, e-mail, February 5, 1999.

125. Scott, “Airbreathing HyperSoar Would ‘Bounce’ on Upper Atmosphere,” pp. 126-130.

126. HQ AFSPC DOMN, *Concepts of Operations far the Phase I Space Operations Vehicle System,* pp. 7, 25.

127. Dale Hill, “Strategic Assessment Center Briefing” (Maxwell Air Force Base: AL, 23 October 1998). See http://sac.saic.com/space warfare/space_warfare.htm.

128. Some maintain that ICBMs are space weapons because the reentry vehicles travel through space. This same logic would characterize a bullet from an M-16 as an “air weapon” because the bullet travels through air. This author maintains that SOV weapons are in effect surface to surface weapons, just like ICBMs, but this is a contentious view.

129. HQ USAF, DCS Air & Space Operations, Directorate of Command & Control, Strategy, Concepts & Doctrine Division, *Space Doctrine and Strategy Issues,* (Washington DC: April 9, 1997), p. 2.

130. Other forms of progress would be to use unmanned RLVs or ground-based lasers that bounce from space-based mirrors to strike targets around the world. While this does not imply that laser weapons are sufficiently powerful to attack hardened targets, it illustrates the concept of technical progress and human proximity to weapon effects.

131. Observations of HQ AFSPC action officers during author interviews February 26, 1999 and Dr William A Gaubatz, “Specific Inputs to National Security Space Master Plan, Space Sortie and Military Operational Space.” (McDonnell Douglas Aerospace, Huntington Beach CA, June 7, 1996), p. 10.

132. Paul Kennedy articulates the point well, “Men’s desire to have the most advanced state of the art weaponry so that their armed services may be able to fight in all possible battle scenarios, produces goods which are increasingly more expensive, more elaborate and much less numerous “ Kennedy, p. 443.

133. However the significant contributions made by carrier-based air in the Korean conflict settled the issue. See Jeffrey G. Barlow, *Revolt of the Admirals: The Fight far Naval Aviation, 1945 - 1950* (Washington DC: Naval Historical Center, 1994), p. 121.

134. Jamie G.G Varni et al, “Space Operations: Through the Looking Glass,” *2025 Study,(*Maxwell Air Force Base, AL: Air University Press, 1996), pp. 227, 233.

135. HQ AFSPC/DOMN, *Concepts of operations for the Phase I Space Operations Vehicle System,* p. 10.

136. The June 25, 1997 docking accident between Mir Space Station and Progress re-supply spacecraft highlights the challenges associated with remotely piloting spacecraft, not to mention the difficulties of autonomous docking. This accident resulted in depressurizing a portion of the space station and almost required an emergency evacuation of the Mir space station. See Craig Covault, "Mir Accident Imperils U.S. - Russian Cooperation," *Aviation Week & Space Technology* (June 30, 1997), p. 21.

137. This statement is based upon DoD missions in orbits less than 250 miles altitude and at less than 60 degrees inclination.

138. Specifically, "The shuttle offers the potential of improving mission flexibility and capability by on-orbit checkout of payloads, recovery of malfunctioning satellites for repair and reuse, or re-supply of payloads on orbit thus extending their lifetime. Payloads would be retrieved and refurbished for reuse and improved sensors could be installed during refurbishment for added capability." Quoted in Robert Frank Futrell, *Ideas, Concepts, Doctrine: Basic Thinking in the United States Air Farce, 19611984*, Vol. 2 (Maxwell Air Force Base, AL: Air University Press, December 1989), p. 685.

139. The Warner Robins Air Logistic Center provided the following cost and flight time data for round trip highest priority airlift: Dover DE to Ramstein AB GE, C-5 17 hours at a cost of $240,000. C-141 18.5 hours at $100,000. C-17s operate from Charleston SC to Ramstein AB GE, 20.5 hours flight time at $150,000. The maximum payload for a C-17 is 170,000 pounds. E-mail from S. Maeurer, WR-ALC/TI, November 19, 1998.

140. The assumption is that there will be some cargo for the RLV to pay for the return trip.

141. This includes inter-theater versus intra-theater, heavy versus light cargo (e.g., M-l tank or pallets), rugged versus prepared landing facilities, and airdrop versus ground offload.

142. In terms of materiel solutions, it is prudent to invest in additional conventional air, land, and sea lift capability. And in the case of non-materiel solutions, the United States can conduct better planning force deployment, pre-position critical equipment, and reduce the "logistics footprint" of units can reduce the need for rapid global transport.

143. HQ AFSPC DOMN, *Concepts of Operations for the Phase I Space Operations Vehicle System, p 9.*

144. U S Air Force doctrine defines space control as "operations to assure the friendly use of the space environment while denying its use to the enemy. This can be order to gain and maintain control of activities conducted in or through the space environment" *Air Force Basic Doctrine,* Air Force Doctrine Document 1, September 1997, pp. 84-85.

145. The concept of space control has two elements, negation and protection. Protection of space-based assets does not mean that satellites must be "escorted" around their orbits, or that the United States must ensure that no commercial losses occur. Protection might be as simple as putting the weight of the U.S. military behind the promise that any attack on a U.S. satellite will be considered an attack on U.S. sovereign property and dealt with harshly.

146. HQ AFSPC/DOMN, *Concepts of Operations for the Phase I Space Operations Vehicle System,* p, 7.

147. *Ibid.*

148 The current U.S. national space policy directs the military to prepare to protect space assets. What the U.S. views as defensive efforts, may be viewed by others as offensive. While this statement can be true for all weapon systems, there is a difference when dealing with the medium of space. The idea of the U.S. "controlling" space, something that is "international" in character as opposed to something contested by two belligerents during a state of conflict, may not meet with intentional approval or support. At some point, U.S. current and future allies may view an increasingly "space-strong" U.S. not as a strong friend and protector, but as a potential aggressor that has grown too powerful. U.S. actions pursuing space control must consider potential unintended consequences, which is made all the more difficult by the relative newness of space control.

149. Varni et. al., p. 210.

150. Dale Hill, "Strategic Assessment Center Briefing "(Maxwell Air Force Base, AL: October 23, 1998). See http://sac.saic.com/space_warfarc/space_warfare.htm.

151. This idea was derived from correspondence with HQ AFSPC/DRS, January 3, 1999.

152. In the early 1980s, the U.S. developed and successfully tested a space control weapon, the F-15 launched anti-satellite system, but decided not field it.

153. Interestingly, the previously mentioned Air Force wargames report identified "military spaceplanes" as favored systems, whose primary uses were space launch and global precision strike, rather than space control. See HQ USAF, DCS Air & Space Operations, Directorate of Command & Control, Strategy, Concepts & Doctrine Division, *Space Doctrine and Strategy Issues,* (Washington DC: April 9, 1997), pp. 10-11.

154. HQ AFSPC DOMN, *Concepts of Operations for the Phase I Space Operations Vehicle System,* pp. 10 - 11.

155. Colonel Henry D Baird, et. Al. "Spacelift 2025: The Supporting Pillar for Space Superiority," *2025 Study,* (Maxwell Air Force Base, AL: Air University Press, October, 1996), p. 118. The Specific statement was "…[lower launch costs] is the key to the affordable use of space. We must work this as a #1 priority. In concert with civil and commercial interests, we must move from a low earth orbit cost of thousands of dollars per pound to hundreds of dollars per pound by 2015. Economies of this scale will enable us to transfer investment to doing things in space vice paying to get there." USCINCSPACE, February 27, 1998, as quoted in Director of Plans. "The Resource Question," *US Space Command Long Range Plan*, p. 1.

156. Paul Kennedy, in *The Rise and Fall of The Great Powers,* makes this *very* point for all today's modem weapon systems, including satellites, "It is clear that today's complex weaponry simply cannot be replaced in the short times which were achieved during the Second World War." See Kennedy, p. 524.

157. Penn and Lindley, p. 153.

158. While the event received publicity, the fact that tactical commanders in Desert Storm had more than adequate communication led most observers to conclude that no need exists for small, light, tactical satellites.

159. Spires, p. 267.

160. *Ibid.,* p. 246.

161. The DoD does not "do" spacelift today, and with the exception of a handful of Atlas launches in the 1960's, never has. Spacelift operations and maintenance functions are conducted by contractors. Uniformed personnel do not turn wrenches or push buttons, they are essentially quality assurance evaluators and safety monitors. Primary duties of U.S. Air Force operations crews on launch day are to verify safety procedures/practices and keep the leadership informed.

162. The Commercial Space Act was signed into law on October 8, 1998. The exceptions to procuring commercial services are specified in Title Three, and include national security objectives, already procured/contracted services, and additional space that is available on shuttle flights, among others. See flp://flp.loc.gov/pub/thomas/cl05/hl702.ih.txt, December 12, 1998.

163. The specific language in the Commercial Space Act 1998, Section 206(b) includes: The Federal Government shall not be required to acquire space transportation services if NASA administrator or in case of a national security issue, the SecAF determines that: (1) a payload requires the unique capabilities of the Space Shuttle; (2) cost effective space transportation services that meet specific mission requirements would not be reasonably available from commercial providers when needed; (3) the use of space transportation services from commercial providers poses an unacceptable risk or loss of a unique scientific opportunity; (4) the use of space transportation services from commercial providers is inconsistent with national security objectives; (5) it is more cost effective to transport a payload in conjunction with a test or demonstration of a space transportation vehicle owned by the Federal Government; or (6) a payload can make use of the available cargo space on a Space Shuttle mission as a secondary payload, and such payload is consistent with the requirements of research, development, demonstration, scientific, commercial and educational programs authorized by NASA.

164. HQ USAF, DCS Air & Space Operations, Directorate of Command & Control, Strategy, Concepts & Doctrine Division, *Space Doctine and Strategy Issues*, Washington DC: April 9, 1997), p. 14.

165. In addition to obtaining a license for each launch from the Department of Transportation, providers of commercial launch services are required to demonstrate their financial responsibility or obtain insurance that will cover third party liability claims of up to $500 million per launch. In the event of a catastrophic failure, the commercial licenses would have to pay up to $500 million, while the U.S. government will pay the next $1.5 billion. Currently, the U.S. government acts as its own insurer for its launches and does not

require a license. (49 USC 70112(a)(1)(A). On 20 April 1999, Senator John McCain (R-AZ) introduced a bill (S.832) that would extend government indemnification of third party liability claims until December 2009. See Robin Squatrito, "Legislative Update" (Peterson AFB, CO: HQ AFSPC/XPPL, May 24, 1999). P. 5.

166. This perspective was articulated by a legal consultant to HQ AFSPC/DOSL e-mail, 1 February 1999.

167. If this were the case, a provision in the Commercial Space Act of 1998 allows the government to use the most cost-effective approach.

168. See http://stp.msfc.nasa/gov/stpweb/x33.

169. Scott, "McPeak, Hecker Head 'Space-Plane' Project," p. 23.

170. See the DC-X Frequently asked questions page. Based upon early cost goals for the Delta Clipper, the price for a space trip was estimated to be less than the cost of a round-the-world trip on the QE II, or from $40,000 to $140,00. See http://www.hq.nasa.gov/office/pao/History/X-33/dc-xa htm, October 8, 1998.

171. Penn and Lindley, pp. 154-156.

172. Scott, "McPeak, Hecker Head 'Space-Plane' Project," p. 23.

173. The Commercial Space Launch Act authorizes the Secretary of Transportation to oversee, license and regulate commercial launch activities (49 USC 70103). The Office of the Associate Administrator for Commercial Space Transportation of the Federal Aviation Administration of the Dept of Transportation (DOT/FAA/AST) carries out these responsibilities. The license certifies that the commercial operator will conduct operations in a manner consistent with public health and safety, safety of property, and national security and foreign policy interest of the U.S. (49 USC 70105(a)(1)). The DOT may establish procedures for safety approval of launch vehicles, reentry vehicles, safety systems, processes, services, or personnel that will be used in conduct of space launch reentry activities (49 USC 70105(a)(2). A license holder must allow the DOT to place an individual as an observer at a launch or reentry, site that the holder uses (49 USC 70106). Information provided by AFSPC DOSL, e-mail, March 3, 1999.

174. In 1996, the number of commercial launches exceeded the number of government launches for the first time. See Director of Plans "Future Strategic Environment," *US Space Command Long Range Plan* (Peterson Air Force Base, CO: March 1998), p. 3. The way that space launch has always been performed involved the use of expendable government rockets that lift-off from government-owned facilities to place government satellites into orbit. The successful transition to privately owned commercial reusable launch vehicles lifting off from private spaceports, carrying foreign payloads into orbit, and then returning to Earth will require fundamental changes in the "business climate." Accordingly, this transition poses substantial challenges to the commercial space launch community.

175. The commercial telecommunications satellite building industry (the largest satellite segment at approximately 85%) does not currently plan to design and build refurbishable satellites. They are moving towards smaller, cheaper individual spacecraft that are replaced with superior technology every 5-8 years, and to "discard" satellites after use.

176. Egan, pp. 15-16.

177. The figure of $20,000 is in 1997 dollars and estimates are derived from Penn and Lindley, pp. 157-158.

178. *Ibid.*

179 *Ibid.,* pp. 156-157.

180. The forecast is for more than 2,700 satellites that are launched through 2017. This forecast excludes "Eastern Military satellites" and Western classified satellites for which no estimates are available. Lehto, "Space Systems Analysis 2," p, 4.

181. "X33, What is X33?" See http://stp.mstc.nasa.gov/stpweb/x33/x33aboout.html, October 8, 1998.

182. Egan, p 15.

183. HQ AFSPC DOMN, *Concepts of Operations for the Phase I Space Operations Vehicle System,* p. 3.

184. Penn and Lindley, p. 158.

185. John J. Bertin, et al, "A Hypersonic Attack Platform: The S3 Concept," *2025 Study* (Maxwell Air Force Base, AL: Air University Press, November 1996), p. 93.

186. Penn and Lindley, p. 159.

187. The majority of ideas presented in this section were obtained from industry sources, who requested that their identity remain confidential. Discussions with these sources occurred between November 17, 1998 and December 4, 1998 through telephone and e-mail.

188. Peter B. Teets, Lockhed Martin President and Chief Operating Officer, told the U.S. Senate on May 20, 1999 that the Venture Star reusable space vehicle project was unable to attract Wall Street investors and would need some form of added government funding or loan backing. It was the first time that Lockheed publicly stated its commercial project, VentureStar, could not be funded through private investment alone. See Robin Squatrito, "Legislative Update" (Peterson AFB, CO: HQ AFSPC/XPPL, May 24, 1999), p. 5. See Honorable Dave Weldon (R-FL), "Congressman Expresses Concern About X-33," Space views (Issue 1999.02.02, February 22, 1999), p. 4. See http://wvww.spaceviews.com/1999/0222.

189. The assumption is continued progress in reducing the size of satellites. Currently, some existing civil, DoD, and national space asset designs require the capability of a Titan IVB booster. There are no commercial variants of the Titan IVB (the Ariane 5 is an approximate commercial equivalent). If the U.S. government continues to build outsized spacecraft, then it will be necessary to maintain a separate heavy lift capability which is a very expensive endeavor.

190. Spires, p. 181.

191. The military functions included an immediate capability, one-way trips with no reusable parts, relatively small size to accommodate deployment schemes, maximum performance and minimum weight, and the ability to be placed on alert. As a result, these designs produced effective long-range nuclear delivery mechanisms that were not optimized for cost. When these ICBMs were pressed into spacelift booster service, they have provided maximum performance and minimum weight, but have not proven to be low cost spacelift solutions. See London, pp. 41 - 42.

192. Current plans are for a self contained Crew Module, which will be carried in the reusable launch vehicle payload bay, to transport humans to and from the space station. The reusable launch vehicle itself is unpiloted. See http://gumbus.jsc.nasa.gov/RLVPM/pmoverview.html. January 21, 1999.

193. One analogy is that when the military needs a new fighter aircraft, it should allow a commercial firm to develop a passenger aircraft, which the military should just use when it becomes available.

194. Two key points for the military to accept with the first generation of commercially viable RLVs is that these will be unmanned and have a response time of roughly seven days.

195. Information obtained through dialogue with members of HQ AFSPC/DOSL, via e-mail February 1, 1999.

196. In the case of ballistic missiles, military personnel provide the functions of transport, assemble, test, maintain, secure, and directly perform or operate all of the tasks that are associated with ballistic missiles. While this is an operationally sound practice for nuclear missions, there is no commercial analog for this practice.

197. Rampino, p. 19.

198. As of this writing, the Air Force was conducting at least five separate studies that should provide quantifiable information on the utility of RLVs. These studies focused on summarizing previous military spaceplane studies as those relate to force enhancement, space support, space control, broad systems applications and force applications Final reports were scheduled to be due between March 1999 and December 1999.

199. HQ AFDC DR, *Space Operations,* Air Force Doctrine Document 2-2, (23 August 1998), p. 10.

200. *Ibid.,* pp. 8-10.

201. *Ibid.,* p 8.

202. *Ibid.,* p 9.

203. *Ibid.*

204. *Ibid.*

205. *Ibid.,* p 8.

206. Muolo, p. 94.

207. HQ AFDC DR, *Space Operations,* p 12.

208. *Ibid.*

209. *Ibid.*

210. London, p. xxvii.

211. HQ AFDC/DR, *Space Operations,* p. 10.

212. Zielger, pp. 6-7, suggests that of the three definitions or levels of space sanctuary, the one in the paper is his recommendation.

213. HQ AFDC/DR, *Space Operations,* p. 12.

214. *Air Force Basic Doctrine,* Air Force Doctrine Document 1 (September 1997), pp. 84-85.

215. HQ AFDC/DR, *Space Operations,* p. 2.

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